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# STATE-OF-THE-ART OF THE MICROSCREEN PROCESS

Engineering-Science, Incorporated
Oakland, California

July 1970

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# STATE OF THE ART OF THE MICROSCREEN PROCESS

**ENGINEERING - SCIENCE, INC.**

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**CINCINNATI, OHIO 45226**

GROUP A TASK REPORT

# STATE-OF-THE-ART OF THE MICROSCREEN PROCESS

Paper For:

FEDERAL WATER QUALITY ADMINISTRATION

By:

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July 1970

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# CHAPTER I

# INTRODUCTION

## INTRODUCTION

The principal objective of this study is to develop a microscreen model as a computer subroutine compatible with the executive program of the Federal Water Quality Administration. The goal for model development is that the model should enable one to predict microscreen performance when the process is used for treatment of secondary effluents as well as capital, operating, and maintenance costs associated with use of the process.

In order to achieve this objective, the study has been divided into 14 functional work areas or tasks. These tasks have been aggregated for task reporting purposes into six task groups, each of which represents a major decision point in the study. The report titles for the six task groups are:

(1) "State-of-the-Art of the Microscreen Process": Group A, (Tasks 2 and 3).

(2) "Operational Mathematical Model for Simulation of Microscreen Behavior", Group B, (Tasks 4 and 5).

(3) "Field Data Acquisition Program for Microscreening Process", Group C, (Tasks 6, 7, 11, 12, and 15).

(4) "Design of Mobile Microscreen", Group D, (Tasks 9, 10, and 13).

(5) "Field Program Report", Group E, (Tasks 14 and 15).

(6) "Analytical Mathematical Model for Description of Microscreen Process Behavior", Group F (Tasks 16 and 17).

The findings of the Group A tasks are summarized in the present report.

## NEED FOR STATE-OF-THE-ART EVALUATION

The framework within which the understanding of the behavior of a process evolves can be described as follows:

(1) Experience and information developed in the initial application of the process provide initially a historical base and ultimately a stochastic basis for describing process behavior.

(2) Initial inquiry and continual application of the process can lead to synthesis of empirical relationships describing process performance.

(3) The utility of the empirical relationships derived through *intuitive* consideration of the process can be expanded as mechanisms are proposed, evaluated, and accepted as germane to the process.

(4) As the usefulness of the empirical relationships continue to expand, an individual can, by synthesis of the implications of the proven empirical relationships and proposed mechanisms for the process, achieve a deterministic explanation for process behavior. At this point, a basis can be established, corroborated, and ultimately promulgated for the use of the deterministic expression to *extrapolate* process behavior.

The activated sludge process provides a classic example of process development through the above steps from an initial point utility to its presently broadening utility. That is, sufficient understanding of the process has developed such that information developed in one application can be transferred forward explicitly to the next application. Unfortunately, the same level of progress has not been achieved in the area of solids separation processes, including the microscreen process. At its present level of development, the microscreen process has been described widely only in terms of stochastic observations on its point utility for specific applications. There have been limited attempts to synthesize the process in terms of either its interactions, or to describe process performance in terms of simple input-output material balances. Thus, one should approach the present state-of-the-art with an awareness first of the need for a system context for the microscreen process, and second that the present information base when interpreted relative to that system context may have only marginal value. For the purposes of the present study, there is a definite need to: establish

a system context for the microscreen process; evaluate the present information base of the process; identify logical points of departure of the microscreen model from present levels of process understanding; and, select from this basis the objectives and role for the microscreen model.

## OBJECTIVES FOR THE EVALUATION OF THE STATE-OF-THE-ART

The evaluation of the state-of-the-art in microscreening involved:

(1) The compilation and evaluation of the present technology for documentation of the theoretical and practical aspects of the microscreening process.

(2) The establishment of a total study context for structuring the interactions occurring in the microscreen process, and for defining a role in the context for the development of the microscreen model to be done in the present study.

The specific objectives which were established for guiding the above activities were:

(1) Develop a total context for the microscreen process, describing the cause and effect relationships which combine to create process behavior.

(2) Describe the development of the microscreen process.

(3) Describe and evaluate surface and depth filtration mechanisms which are applicable to the microscreening process, and select the appropriate mechanisms for the model.

(4) Establish the present level of understanding of the microscreen process and its interactions relative to the process context.

(5) Identify the role of the microscreen model in advancing present understanding of the process and document the information needs required to develop and verify the model.

# CHAPTER II

# THE MICROSCREEN PROCESS

## THE UNIT OPERATION

Microscreening is a special case of filtration in which the medium (microscreen) is a membrane such as woven wirecloth or perforated plate. Microscreens can have apertures as small as 10 microns and have been used for the screening of drinking water supplies and secondary effluents from activated sludge and trickling filter effluents in addition to wastewaters from numerous industrial processes. The commonality among the various types of microscreens is in the use of a drum mount for the medium, part of which is submerged in the liquid being screened in such a way that the flow is outward through the medium. The medium is usually cleaned continuously by air or water jets and the solids concentrate removed from the medium is transferred as a slurry to disposal.

Microscreening, when viewed at the highest aggregate level, involves the passing of a suspension through a moving medium. The suspended particles which are removed may be discrete (mineral) or flocculant (organic or non-organic) and will vary in size from colloidal ($\leq$ 1 micron) to coarse suspended particles. Solids separation by microscreening is accomplished by a series of complex interactions between three phases: a moving solid phase (the screen and cake); a discontinuous solid phase (the material to be removed); and a liquid phase (usually water). The two fundamental system aspects of microscreening are: the screening cycle during which the suspended solids are removed, and a clarified effluent is produced; and the backwash cycle, which involves flushing the collected solids from the medium. The screening cycle is an operation analogous to the declining rate filter; as the screen passes from submergence to emergence during the screening cycle, the headloss characteristics of the developing cake increase and cause a concurrent decrease in the throughput rate. The screening cycle is terminated when a segment of the medium emerges from the liquid pool. During the backwash cycle the accumulated solids are removed from the medium by the several mechanisms usually associated with hydraulic, air, or sonic

cleaning. Generally, microscreen effluent water is used for hydraulic cleaning. The yield of the microscreen is the difference between the quantity of water produced during the filtration cycle and the quantity of water consumed during the backwash cycle.

## SYSTEMS CONTEXT FOR MICROSCREEN PROCESS

### Approach

The microscreen process can be described functionally as a sequence of interacting elements which function to convert, separate, or dispose of the solids in a liquid stream. The systems framework which is selected to interlink the elements together should provide a basis for synthesizing the behavior of the process while at the same time promoting a commonality of process understanding among the groups (i.e., designers, operators, regulators, and researchers) interested in the process. The two alternative system perspectives which were considered were: linear or near-linear, open systems as embodied in the classical approaches to filtration; and dynamic feedback, or closed systems. In the present study, the linear system perspective was rejected because linearity has lead to diversity, rather than synthesis, of interpretation of the types of solids separation processes and has provided little or no driving force for unification of approach to inquiry. The systems context selected for the study was that of Environmental System Dynamics, as discussed below.

### Environmental System Dynamics

Environmental System Dynamics is the concept developed at Engineering-Science, Inc. for the description of the dynamic behavior of feedback systems operative at all levels in the environment. Dynamic feedback systems are those in which the time-phased behavior of the system is significant and is determined by the feedback interactions between the components of the system.

### Application to Process Evaluation

There are several basic premises in the application of Environmental System Dynamics (ESD) to process evaluation. The foremost premise is that the structure of the model can be determind through an examination

of the process. The behavior of the process and its components is determined by the nature of the interactions between components in a sense of sequentially and cyclically related components. Another premise is that process behavior is also determined by control measures which are effected in the process when the perceived or actual value of a parameter (such as actual headloss) differs from a desired value (available head). The final premise of the ESD approach is that the behavior of most systems which have feedback is counterintuitive, i.e., cannot be predicted merely by a consideration of the components of the system.

The understanding of process behavior can be aided by use of both conceptual and simulation ESD models. The conceptual model has its primary value in defining the components and the interactions of components. Inconsistencies in the conceptual model indicate errors in the perception of the process. The simulation model has its primary value in determination of the validity of the nature of relationships between components and the nature of the control measures, leading to a description of process behavior over time. The compatibility of the simulation model with process behavior is a measure of either the perception of the process or of the suitability of the simulation. The simulation model is useful only when behavior over time is of primary interest. As such, the simulation model is an extension of, not a substitution for, the conceptual model.

Proposed Microscreen Concept

The process system shown in Figure II-1 is proposed as the basic context for considering the microscreen process from all points of interest. The arrows of this figure can be interpreted as ***has an effect on after a time delay***; and each of the elements represents a functional interaction occurring in a closed loop which combine to establish a continuity of particle and liquid flows into, through, and from the microscreen medium.

The elements of the microscreen process can be categorized generically as associated with solids transport, liquid transport, or the physical unit. The elements associated with solids transport are: solids character;

desired and actual solids emission rate; solids input rate; solids retention; and filter medium. Elements associated with liquid transport are desired and actual liquid transport rates. The elements associated with the physical unit are filler (or medium), headloss, available head, and backwash. The information requirements for each element are listed in Table II-1; it is noteworthy that each element is quantifiable either as a rate or a level in the total system context.

Interpretation of the systems context in Figure II-1 should consider three factors: the closed or feedback loops operative in the system; the objectives for control of the system; and the distinction made between the elements of solids retention and filtration medium.

Feedback Loops and Objectives

A feedback loop is formed by a closed pathway of elements connected sequentially. The premise of the feedback loop is that the time-phased behavior of an element is determined by the system interactions initiated within and feeding back to the element. One such feedback loop in Figure II-1 is the sequence: actual liquid throughput rate - difference (between desired and actual liquid throughput rate) - filler (screen) - solids retention - filter medium - headloss - difference (between headloss and available headloss) - actual liquid throughput rate. For example, an increase in the difference between desired and actual throughput rate (accomplished by adjusting an actual throughput rate) will require a change in the rate of rotation of the filler, which in turn will adjust the surface density of retained solids. The headloss character of the unit is defined by the resistance of the filter medium (the combination of filler and retained solids); if the headloss resulting from the adjustment in actual liquid throughput rate is excessive with respect to available head, a readjustment of the actual liquid throughput rate is required. On a second iteration, a lesser actual liquid throughput rate may be selected so that the process stabilizes at a headloss less than the available headloss.

There exist a number of additional feedback loops in the systems context, defining interactions between or among:

(1) Solids retention, filter medium, headloss, and backwash.

TABLE II-1

ELEMENTS AND INFORMATION REQUIREMENTS FOR

SYSTEMS CONTEXT OF MICROSCREEN PROCESS

| Element | Information Requirements |
|---|---|
| Liquid Throughput Rate | Influent liquid flow rate; liquid physical properties |
| Solids Input and Emission Rate | Mass rates for dissolved, colloidal, and suspended solids |
| Solids Character | Type of pretreatment; particle description; filtrability index; particle size distribution; particle shear strength |
| Filler (fabric) | Nominal aperture; weave; material; clean screen headloss factor; effective pore (or particle trapping) diameter; and rate of presentation |
| Solids Retention | Residual retention of dissolved, colloidal, and suspended solids on filler after backwash; retention of dissolved, colloidal, and suspended solids on filler during screening cycle (both retentions analogous to a surface density (mass/area) |
| Filter Medium | Effective pore diameter; cake porosity, depth, and density; compolsite headloss character; solids separation mechanism |
| Backwash | Applied rate of backwash; net rate of backwash, pressure; cleaning efficiency |
| Headloss | Pressure drop |

(2) Solids emission rate, solids character, and solids retention.

(3) Solids retention and filter medium.

(4) Backwash, filter medium, solids retention, and solids emission rate.

All of the important loops contain a *difference* between a desired and actual level of an element, and a single difference may be shared by more than one loop. The *desired level* effecting the difference represents the operating objective or goal which provides the driving force for control of the feedback loop. Objectives represent the desired level of an event which, when compared with an actual or perceived level, can lead to specification of the direction and magnitude of adjustment required.

Three *operating objectives* and *differences* are included in the perspective of Figure II-1: liquid throughput rate; solids emission rate; and headloss. The desired liquid throughput rate controls the difference between desired and actual solids emission rates, requiring changes in either the solid character and solids retention and/or in the backwash to adjust the actual solids emission rate. The available headloss is a control in the backwash-filter medium-headloss loop, the purpose of which is to attenuate the effects of changes made in the first and second loops on the filter medium and solids retention; i.e., changes in these latter elements as a result of adjusting solids input and liquid throughput rates will lead ultimately to changes in the headloss character of the filter medium and an adjustment of backwash efficiency.

It is apparent from the feedback loops interrelating the operating objectives, actual levels, and variables that the microscreen process is dynamic and that the adjustment of one variable can act to amplify or attenuate actual levels in a manner which may not be intuitively predictable.

Solids Retention and Filter Medium

A foremost factor in the systems context is the distinction made between solids input rate (a rate), solids retention ( a level of

stored solids), and filter medium (the physical, chemical, and biological medium in which solids are retained). Solids input rate is a loading factor which is a function of hydraulic flow rate and input solids concentration. Solids retention is the inventory of dissolved, colloidal, and suspended solids stored on the fabric at any point in time and space. Solids retention can be depicted graphically as shown in Figure II-2, in which retained solids are comprised of residual carryover from backwash plus solids retained during the screening cycle. Solids retention can be characterized by a surface density parameter.

The most important commonality of the systems context is the filter medium, which is comprised of the solids retention mechanisms and components each operative at a different level in the medium. The filter medium is shown in an expanded context in Figure II-3. The components of the medium are water, suspended solids, colloidal solids, dissolved solids, and the filter. The mechanisms of the medium are those related to inertial forces, electro-forces, concentration forces, and chemical forces. Solid arrows define the mechanism interactions and dashed arrows define the component interactions *inter se* and with the mechanisms. The aggregate interaction of the mechanisms at the lower level and the components at the higher level serves to establish the utility of the process for a specific application, such as water treatment or wastewater treatment.

The approach to defining the filter medium has two basic assumptions. First, all mechanisms described in the literature on filtration for accomplishing transport and attachment of particles are valid and operative at levels determined by the components and the interactions between mechanisms, and second, that the interactions between the mechanisms and components in terms of producing a filtration media can be integrated. Within this framework, all of the existing fundamental knowledge has a level of applicability in predicting the behavior of the filtration process, i.e., the removal and retention of solids occur in a continuum in which the mechanisms responsible for these phenomena vary in importance at any point in the medium.

The filter medium is the factor controlling the solids removal and hydraulic properties of the microscreen. The filter medium will be

an integration of the nature of the particles being separated and the dominant operative mechanisms, the net result of the integration being a composite filter-retained solids medium with particle trapping and headloss-generating characteristics.

## SOLIDS RETENTION MECHANISMS

### Types of Mechanisms

The filter medium element (Figure II-2) which contains the mechanisms is the crucial function in the microscreen process controlling the overall responsiveness of the process. The mechanisms which may be responsible for solids removal or retention in the microscreen process are directly analogous to those applicable to surface and cake filtration in granular bed filtration and include:

(1) Mechanical screening.

(2) Gravity settling.

(3) Interception.

(4) Impaction.

(5) Brownian diffusion.

(6) Molecular forces.

(7) Electrostatic forces.

(8) Electrokinetic forces.

(9) Chemical forces.

The important physio-chemical factors affecting these mechanisms include the following:

(1) Temperature.

(2) pH.

(3) Ionic strength.

(4) Mean fluid velocity.

(5) Hydrodynamics of flows through beds.

(6) Size, density, and concentration of dispersed particles.

(7) Surface characteristics of both solid phases (the suspension and the media) and strength characteristics (shear potential) of the suspended particles.

(8) Physical size characteristics of filter medium.

(9) Depth, porosity, compressibility, and pore size of cake formed in media.

(10) Type and concentration of chemicals added preceding screening (inorganic coagulants or polymeric flocculants).

Before the above solids retention mechanisms can be considered and evaluated for their applicability to the microscreen process, it is apparent that an inquiry framework is needed to establish the context in which the mechanisms were developed and have applicability for predicting solids removal. As a starting point it is generally agreed that the removal of a suspended particle involves both the transport of the particle to the surface of the media and the attachment of the particle to the media. Therefore, the effective removal of particles in the microscreening process depends on the successful execution of these two sequential steps, and the control of the process depends on identifying the controlling step in each situation.

The mechanisms involved in the transport step have not been clearly identified, but may include Brownian diffusion, direct interception, impaction, sedimentation, and long-range attraction due to surface forces such as van der Waal's forces and forces of electrical origin. Brownian diffusion of colloidal particles may be significant since a concentration gradient will develop in the vicinity of the media surface as particles are deposited. Fluid streamlines which bend through the tortuous interstices of the media may carry the particles to the media surface. Direct interception occurs when the center of a suspended particle comes closer to the collector surface than its own radius. If particles do not adhere to the bending fluid streamlines when approaching an obstacle (media grain) but tend to continue in the original direction of flow, they may be carried to the media surface

by their own inertia, a mechanism known as impaction. Fluid streamlines may also transport particles to stagnant areas in the bed, where the particles may be removed by sedimentation. Finally, it has been hypothesized that attractive surface forces of a molecular or electrical nature may extend far enough into the bulk of the liquid to attract suspended particles to the surface.

Particle attachment can be accomplished by several mechanisms of either a physical or chemical nature. Particles may be physically supported in clogged interstices or in surface niches on the media surface. They may be adsorbed on the media surface due to specific ionic interactions or hydrogen bonding. If the van der Waal's forces of attraction between the particles and the media surface are greater than electrostatic or other forces of repulsion, then the probability of attachment by adsorption will be increased. Attachment may also be enhanced by electrokinetic forces which are caused by the continuous shearing of the electrical double layers surrounding the media particles. In some instances particle attachment can be significantly improved by the use of inorganic or organic coagulants. It has been postulated that the dominant mechanisms in such cases may be specific chemical forces arising from the bridging between the hydroxo-metal complexes or organic polyelectrolytes, the suspended particles, and the filter grains.

Evaluation of Mechanisms

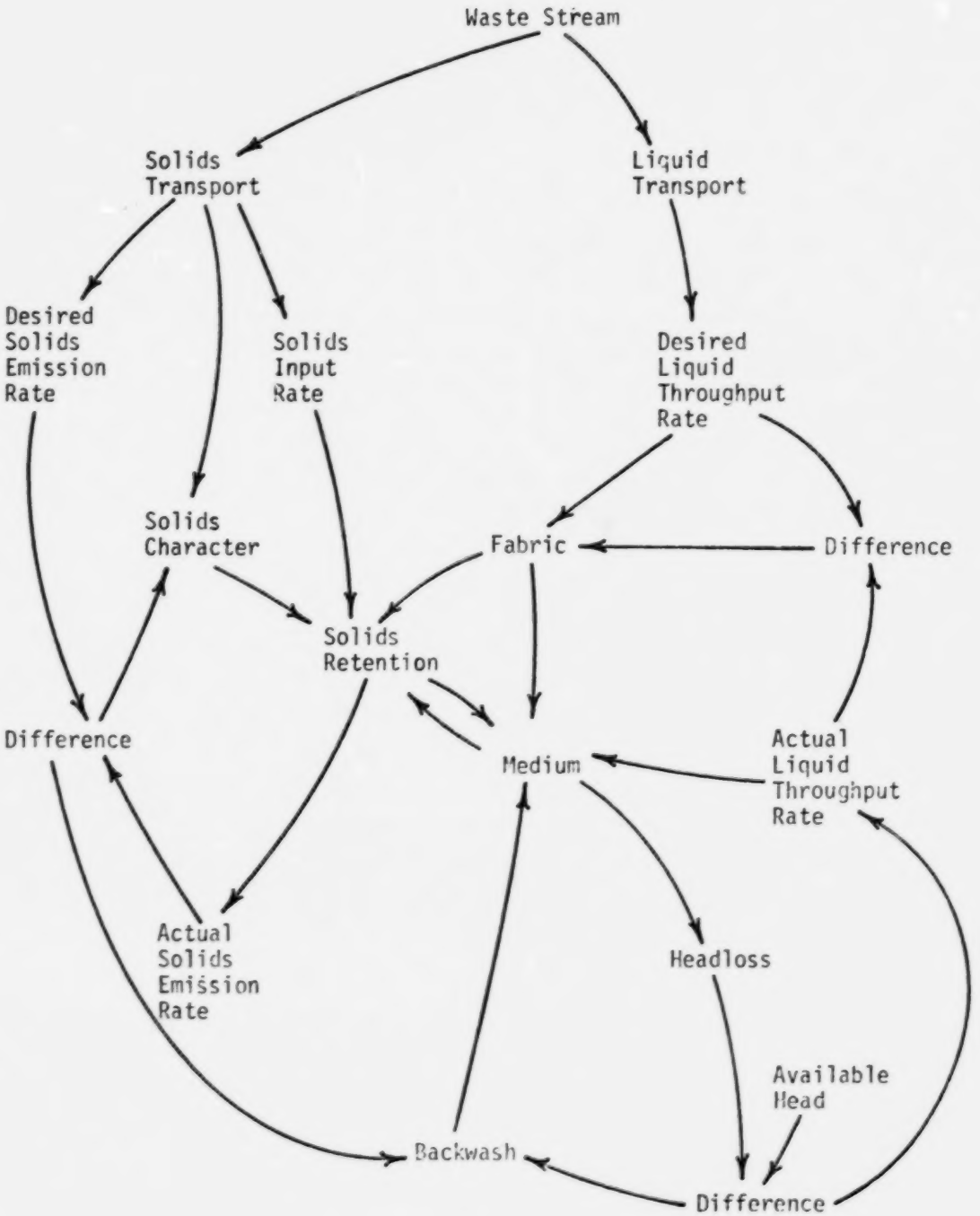
An evaluation of the applicability of the solids retention mechanisms to the microscreen process should include a consideration of the nature of the particles being removed, the nature of the controlling mechanism (transport or attachment), and the location of the particle removal (surface vs. depth). An inquiry framework for the evaluation is shown in Figure II-4. The initial premise of the framework is that an identified need for the separation exists. The initial inquiry is to establish if the solids are discrete (i.e., susceptible to separation). If the solids are not discrete, it is then necessary to establish whether the solids are colloidal or dissolved, in which case flocculation (for colloidal solids) and coagulation or precipitation (for dissolved solids) are indicated.

The second inquiry is to establish if solids removal is transport-controlled, in which case the inquiry proceeds to establish whether or not removal occurs at the surface. In either case (at the present level of definition of removal mechanisms), the applicable mechanisms include gravity settling, interception, impaction, molecular forces, and Brownian diffusion.

The third inquiry addresses whether or not removal is attachment-controlled, given the conclusion that removal is not transport-controlled. If removal is not attachment-controlled, then no removal whatsoever can occur. If removal is attachment-controlled and occurs either at the surface or in the cake, the following mechanisms are applicable: screening (at the surface); straining (in-depth); molecular forces, electrostatic forces; electrokinetic forces; and chemical forces. In the event that removal does not occur either at the surface or in the cake, then shear stress (particle shear) is the only mechanism that is operative, with the result that smaller particles capable of penetrating the medium are produced.

It is apparent from the above inquiry that no one theoretical mechanism may be applicable to the totality of solids retention phenomena associated with microscreening. The ultimate resolution of which mechanism or mechanisms can be used to describe the microscreen process depends upon a determination of the relative importance of the several mechanisms effecting removal in any given situation to the overall performance of the microscreen. Discussion in Chapter III addresses the usefulness of the foregoing mechanisms for defining the environment in which the design and development of microscreen systems should take place, as a basis for selecting the mechanism to be used in the microscreen model.

FIGURE II-1




PROCESS SYSTEM FOR MICROSCREENING

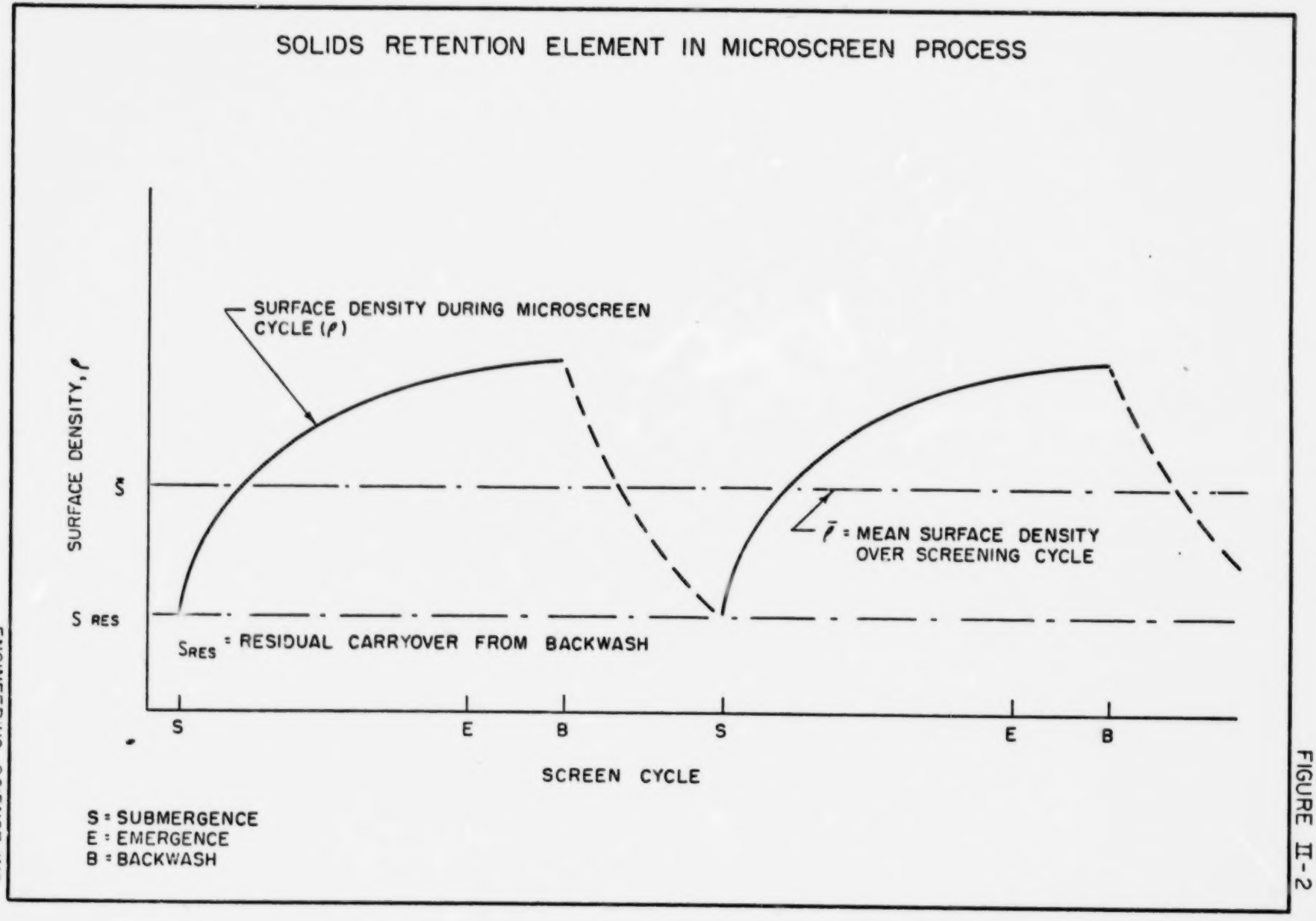

SOLIDS RETENTION ELEMENT IN MICROSCREEN PROCESS
SURFACE DENSITY DURING MICROSCREEN CYCLE (ρ)
SURFACE DENSITY, ρ
S
S RES
$\bar{\rho}$ = MEAN SURFACE DENSITY OVER SCREENING CYCLE
$S_{RES}$ = RESIDUAL CARRYOVER FROM BACKWASH
S
E
B
S
E
B
SCREEN CYCLE
S = SUBMERGENCE
E = EMERGENCE
B = BACKWASH

FIGURE II-2

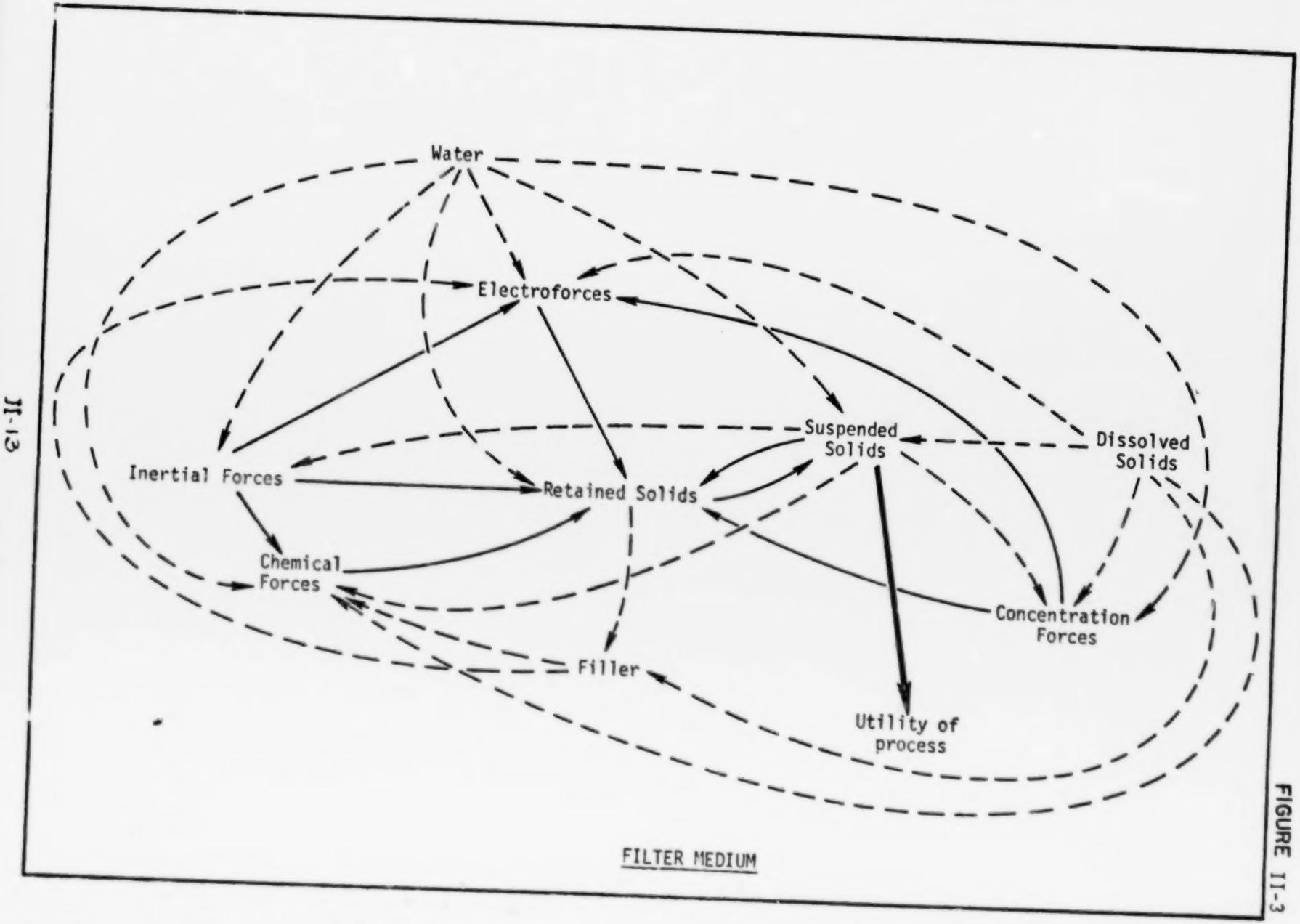
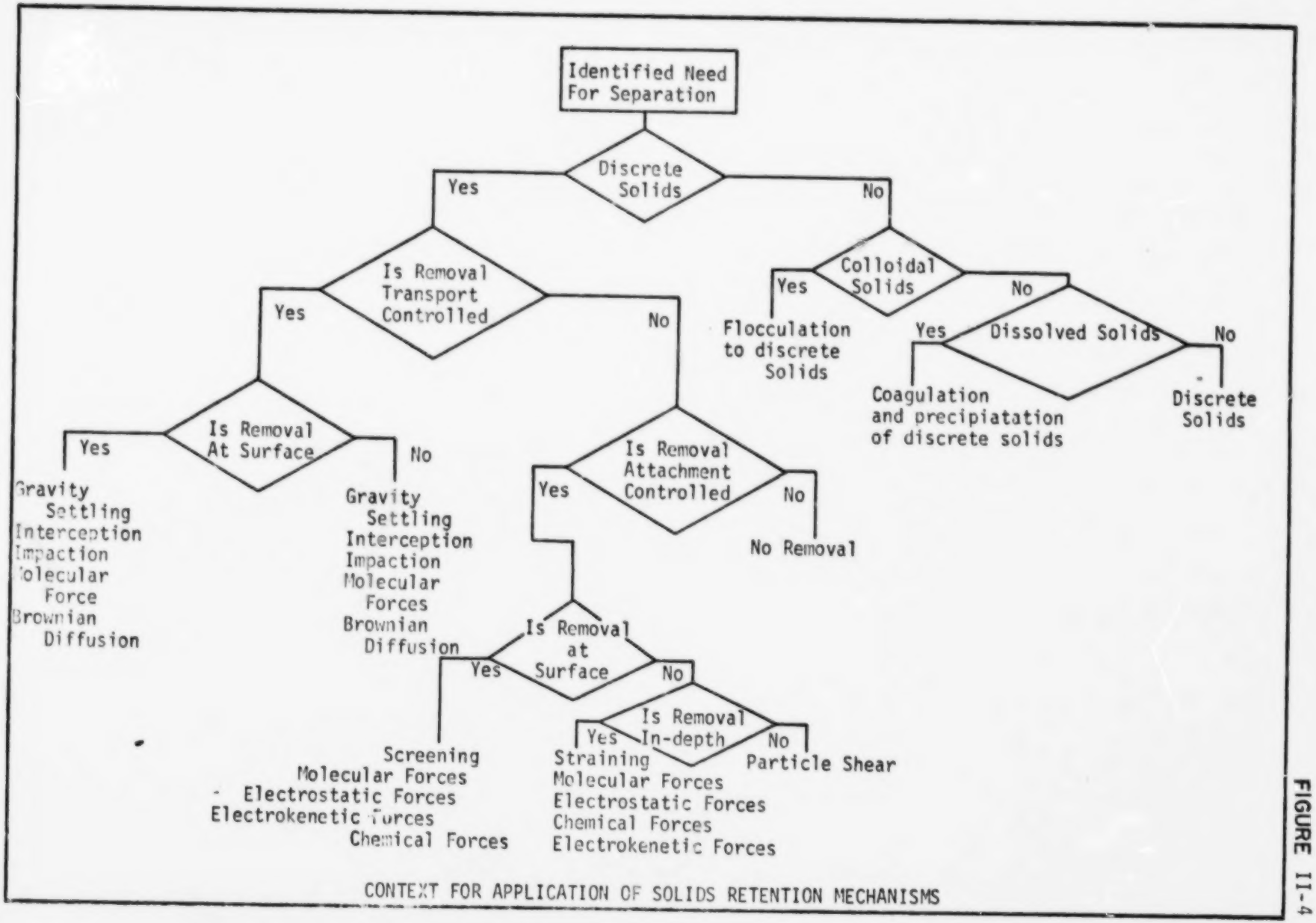

Water
Electroforces
Suspended Solids
Dissolved Solids
Inertial Forces
Retained Solids
Chemical Forces
Concentration Forces
Filler
Utility of process
FILTER MEDIUM

FIGURE II-3




CONTEXT FOR APPLICATION OF SOLIDS RETENTION MECHANISMS

FIGURE II-4

# CHAPTER III

# MECHANISMS IN THE MICROSCREEN PROCESS

The literature on solids separation processes contains a wealth of information on the types of mechanisms operative in the flow of liquid and solids through the processes. The three classes of mechanisms relating to solids retention, hydraulic, throughput, and particle shear have particular reference to the microscreen process and are reviewed in this section

## SOLIDS RETENTION MECHANISMS

### Mechanisms

The solids retention mechanisms identified previously include mechanical screening; gravitational settling; interception; inertial compaction forces; electrokinetic forces; convective forces; and chemical forces. All of these mechanisms, as discussed below, can be considered as describing either a transport step (in which the particles are moved to the surface of the medium) or an attachment step (in whic the particles adhere to the medium).

#### Mechanical Screening

Suspended particles whose sizes are larger than the sizes of the pore spaces of the microscreen fabric will be removed mechanically by the screen. This is the simplest and most popular mechanism proposed for microscreening. Screening is not responsible for the transport of particles because this mechanism becomes important only when the particles have reached the media surface. However, screening will contribute to the attachment step due to physical support of removed particles by the media. When screening occurs, most of the suspended materials are removed as a thin layer or mat on the screen surface. This results in effective removal of particles but the rate of headloss buildup may be rapid due to extensive clogging of the pore spaces. This type of removal is essential to the performance of *thin film* filters such as the microscreen and to optimal solids recovery from such filters.

Although mechanical screening can be used to describe the removal of particles larger than the size of the interstitial pores its validity as a concept of removal within the depth of the media (i.e., straining) has not been verified. However, because of the shape of the interstitial spaces on the screen and in the overlying cake formed, and because of the random motion of the particles moving through the cake and screen it is probable that this type of removal in the microscreen is also significant.

Gravity Settling

Many investigators have hypothesized that gravity settling of the particles onto the top of a filter media or within the interstices of the media may be a significant removal mechanism; this mechanism to some level is also applicable with the microscreen. As postulated gravity settling is essentially a transport mechanism for which the density difference between the particles and the fluid serves as the driving force. In this context, the pores of the media are considered to be small shallow settling basins in which particles settle to the media surface due to he force of gravity. The gravitational force may also contribute to the attachment of particles to the upstream media surface normal to the direction of flow; however, this is not thought to be a significant aspect of overall removal by settling.

The parameters controlling this mechanism have not been satisfactorily related to the removal efficiency of granular media, nonetheless to microscreening media, but it is apparent that for particles with densities nearly equal to that of water (e.g., alum or iron flocs, bacterial cells), the gravitational force would be neglible in comparison to hydrodynamic forces acting on the particles. Furthermore, if gravity settling were the controlling mechanism, particles would not be removed on the underside of the media which is contrary to reported observation. Agrawal (Reference III-1) has shown that for suspended material with specific gravities of less than 10 microns will be rather small. It appears that the mechanism of gravity settling cannot explain the effective removal of low density flocculated particles which is commonly observed in water treatment practice.

Interception

In an idealized picture of fluid flow through the media, suspended particles subjected to the viscous forces of the fluid will follow fluid streamlines as they bend around in the congested interstitial region of the cake and fabric. If the streamline is such that the particle is within a distance equal to, or less than, the particle radius of the media then contact will be made between the particle and the media. By definition this is a transport mechanism and is not involved with the attachment step. That is, a collision between a suspended particle and the media does not imply attachment.

Agrawal (Reference III-1) reports that the efficiency of contact of an individual spherical collector is proportional to the square of the interception parameter (R), where R is given as the ratio of particle size to media size (dp/dm). If the probability of an effective collision is known, then the possible contribution of interception to removal can be estimated analytically. However, the applicability of this approach in practice is subject to some difficulties. Particles may not follow fluid streamlines in the cake or screen due to variations in viscous forces within a channel. A particle will experience asymmetrical forces on its surfaces, and tend to drift between streamlines. Secondary flow effects of local turbulences in the pores may also cause particles to deviate from the fluid streamlines. These phenomena may increase the probability of contact, thereby decreasing the likelihood that interception is a limiting mechanism for transportation.

Impaction

This mechanism, frequently referred to as inertial impingement, is used to define the situation when the inertia of the suspended particles is such that they do not follow the bending fluid streamlines when approaching an obstacle; but tend to continue in the original direction of flow, thus increasing the probability of contact with the screen surface. Impaction is essentially a transport mechanism. Its relative contribution to particle transport has been analyzed by Agrawal (Reference III-1). The relevant parameter of this mechanism is I, which equals $\rho_p d_p^2 V_o / 9\mu\, d_m$, where $\rho_p$ is the particle density, V is the superficial fluid velocity,

and μ is the viscosity. Under most conditions encountered in water filtration, the magnitude of the inertial parameter (I) is on the order of $10^{-5}$. Agrawal has show that, for this magnitude of I, impaction is not a significant removal mechanism.

Brownian Diffusion

As particles are removed from the fluid, a concentration gradient will develop between the media surface and the bulk of the liquid. It has been established that the mass flux of suspended solids is proportional to this concentration gradient, and that Fick's first law of diffusion (mass flux = $D_{BM}$ dc/dx) is applicable to this system. $D_{BM}$ is the coefficient of Brownian diffusion of the particles and dc/dx is the concentration gradient in the x direction. The coefficient of Brownian diffusion is inversely proportional to the particle size; thus, for colloidal particles, Brownian diffusion may be a significant transport mechanism. Agrawal (Reference III-1), O'Melia and Stumm (Reference III-2), and others have shown that Brownian diffusion is a significant, and may be the dominant transport mechanism for particles of one micron or less in size.

Molecular Forces

Particle combination processes such as coagulation occur when the attractive forces between particles exceed the repulsive forces between the particles. One form of attractive force acting on colloidal particles is the same as that which has been found to exist between atoms, molecules, and microscopic particles; these forces are referred to generically as the London-van der Waal's forces of attraction. The disctance over which these forces are effective is very limited; it is usually measured in terms of Angstroms.

The molecular force of attraction between two individual atoms varies inversely as the seventh power of the distance between atoms. These forces of attraction do not decay as rapidly for the interaction between two plates or between a plate and a sphere as they do for two spheres. The London-van der Waal's forces existing between a plate and a sphere varies inversely as the cube of the distance separating them and directly with the radius of the sphere. These two factors account for the relatively long range effect reported for these attractive forces under the latter conditions (Reference III-3).

The influence of molecular forces on the transport and attachment steps of filtration has not been definitely established. Under certain specific and somewhat unique conditions both steps may be affected by these forces. In the absence of more dominant forces, such as hydrogen bonding, ion exchange, or interaction supported by polyelectrolytes, it is possible that molecular forces of attraction are responsible for particle attachment to screen media. To be effective in the transport step the molecular forces of attraction would have to extend into the bulk liquid with sufficient strength to overcome the forces of repulsion and those forces, viscous and gravitational, which act to carry the particles by the screen media.

The relative significance of molecular forces in granular bed filtration has been analyzed by Agrawal (Reference III-1), Mackrle and Mackrle (Reference III-4), and Ives and Gregory (Reference III-5). The latter investigators have concluded that the range of electrostatic and molecular forces is less than 500 Angstroms in most natural waters containing moderate concentrations of dissolved salts; and they conclude that such forces cannot be responsible for particle behavior in the bulk of the liquid contained in the pore spaces. Agrawal (Reference III-1) has developed a relationship between molecular forces and removal efficiency. His analysis, based on the consideration of hydrodynamic drag and molecular forces, shows that the molecular forces of attraction are insufficient to cause the high degree of removal of small particles which is observed in practice. Thus, based on these results it is improbable that molecular forces of attraction have any significant influence on particle transport.

No investigators have analytically or experimentally shown that molecular forces of attraction control the attachment step in filtration. Conceptually it is apparent that a particle which comes in contact with the surface of a media will be attached if the net forces of attraction are greater than those tending to repulse or detach the particle. The latter parameters include electrostatic repulsion, hydrodynamic shear forces, and a gravitational force. However, O'Melia and Stumm (Reference III-2) suggest that when hydroxometal complexes or polyelectrolytes are used in granular bed filtration, molecular or other surface forces may no longer be involved, to any significant degree, in the attachment step. The same may be true

in microscreening.

Electrostatic Forces

A solid in contact with a liquid acquires a surface charge. The nature and origin of this charge depends on the solid; and may be due to dissociation of inorganic groups, charge transport across the interface by ions common to the solid lattice, specific adsorption of electro-potential-determining ions, deformation of polarizable ions on the surface, or other causes. To satisfy the condition of electroneutrality, an equivalent amount of ionic charge of opposite sign to that of the particle is distributed on the liquid side of the solid-liquid interface forming an electrical double layer.

An idealized model of double layer around a spherical particle is shown in Figure III-1. This conceptual model is based on the Stern modification of the Guoy-Chapman theory as discussed by Kruyt (Reference III-6). According to this model there is a monolayer of adsorbed, immobile or fixed, counter ions in the liquid phase of the interface; this is the so-called Stern layer. Adjacent to this fixed counter ion layer is the diffuse layer consisting of an ionic atmosphere comprised of both anions and cations whose net charge is of a maximum near the fixed layer and decreases asymmetrically to zero within a few Angstroms of the solid surface. This diffuse layer is referred to as the Guoy-Chapman layer.

The Nernst potential defines the total potential drop between the solid and the bulk liquid; and is equivalent to the chemical potential. In addition there is the Stern potential which is the potential between the fixed counter ion layer and the bulk liquid; and the potential between the surface of shear and the bulk liquid which is referred to as the Zeta potential. Although this latter potential, the Zeta potential, as currently and routinely measured is system dependent, it is the parameter most widely used to characterize the electro-characteristics of particles. The thickness of the double layer, that is the extent of the electrical field around the particle, is determined by the total concentrations of ionic species in the solution. The thickness of the double layer can be approximated using the following expression (Reference III-2):

$$\psi = \sqrt{\frac{\varepsilon RT}{4\pi e^2 \sum_i C_i Z_i^2}} \qquad \text{(III-1)}$$

where: $\psi$ = thickness of double layer

$\varepsilon$ = dielectric constant of the liquid

R = gas constant

T = absolute temperature

e = electronic charge

$C_i$ = molar concentration of ionic species i

$Z_i$ = ionic charge of $i^{th}$ species

For a $10^{-4}$ M NaCl solution the thickness of the double layer, as calculated with the above expression, is about 300 Angstroms. Because the concentration of ionic species in most filtration systems is greater than $10^{-4}$ M, the double layer will extend only a small fraction of a micron away from the surface of the particle.

The charge assumed by the solids is determined by the specific substance comprising the solids and the ionic environment of the solids. Thus, all the solids derived from a given substance will exhibit the same charge in a given environment, and will, as a group, exhibit different charges in different environments. In addition, solids of different substances may demonstrate different charges under the same environmental conditions. Therefore, the inter-particle forces resulting from the electrostatic charges on a particle may be either forces of attraction or repulsion. These forces come into effect only when there is an overlap between the diffuse layers. The complex interactions which occur when the distance between the two solid surfaces is, or approaches, the same order of magnitude as the extent of the double layer have been analyzed by Overbeck (Reference III-7), Gregory (Reference III-8), and others. These investigators have concluded that in most solid-liquid systems the potential energy due to the double layer decays rapidly with distance from the surface of the solid and is essentially zero only a few Angstroms into the liquid; exceptions to this are systems containing distilled or demineralized water. Thus, the attractive or repulsive forces due to double layer interactions are short range in character and become important only when the distance between solids is on the order of several hundred Angstroms or less.

On the basis of the above considerations it does not appear that the electrostatic forces constitute a rate controlling mechanism in the particle transport step. However, if a particle is carried to within a micron or less of the screen surface, electrostatic forces may have either a positive or negative influence on the attachment step. The degree of the influence will be determined by the sign of the charge and the extent to which other factor are dominating the attachment step.

Electrokinetic Forces

For a dynamic system in which the liquid is moving past, or across, the solid surface the double layer, or a portion thereof, is continuously sheared away from the screen surface, setting up a net upstream-downstream electropotential which is referred to as the streaming potential. Agrawal (Reference III-1) has hypothesized that this electropotential is in itself a significant factor in the transport and attachment of particles to the screen surface.

The streaming potential is one of four electrokinetic phenomena which can occur in dynamic solid liquid systems as a consequence of the existence of a double layer. A streaming potential is produced when a liquid flows through a capillary, porous plug or granular media. According to the Stern concept of the double layer a slip or shear plane develops at or near the fluid boundary of the Stern layer. As the liquid stream moves past the solids surface, it carries with it a portion, or all, of the diffuse layer resulting in the generation of an electro-potential as a consequence of ionic transport. Therefore, there is an accumulation of the dominant ionic species in the double layer at the downstream end of the system and a deficiency of these species at the upstream end of the system. This convection current is opposed by a conduction current which is generated due to the imbalance of ionic species across the system. At steady state the convection current which is proportional to the hydrostatic pressure, P, is balanced by the conduction current which is proportional to the streaming potential, E. Thus E is proportional to P as follows (Reference III-3):

$$\frac{E}{P} = \frac{\varepsilon \zeta}{4 \pi \eta K} \qquad \text{(III-2)}$$

where: $\varepsilon$ = dielectric constant of the bulk liquid

$\zeta$ = zeta potential (assumed to be equal to the potential drop between the shearing plane and the bulk liquid)

$\eta$ = viscosity of the liquid

K = specific conductance of the liquid

Several basic assumptions which are incorporated in the development of the above equation may be invalid under some conditions. The dielectric constant and the viscosity of the bulk liquid are assumed to be applicable in the region of the double layer. This assumption could be a source of considerable error if these two parameters are not the same in the double layer as in the bulk and if the ratio of the two varies between the bulk and the double layer region. In addition, it is assumed that the conduction current depends only on the conductance of the bulk liquid; the degree to which this condition is satisfied depends on the ionic strength of the bulk liquid. The surface conductance of the solids is an important component of the total conductance current for distilled water or demineralized water environments. The radius of curvature of the pores in the media must be larger than the thickness of the double layer for the above operation to be applicable. The conduction current creates an electro-osmotic effect which opposes the normal hydraulic flow; for very small orifices this opposing flow may be sufficient to reduce the E/P ratio (Reference III-3).

The principle application of streaming potential measurements has been for the determination of the zeta potential prevailing in a dynamic system. Streaming potential measurements are accomplished using an electrode system and a high impedance voltmeter; the measurements are made under conditions of constant hydrostatic head. Equation III-2 is used to calculate the zeta potential employing the preceding measured values and appropriate values for the other variables of the equation. However, in spite of the simplicity of the experimental system, numerous sources of experimental and analytical errors are encountered which in part explain the reported disagreements between the results of different investigators.

The prior history of the filter media may have a significant effect on the calculated zeta potential. Impurities in the solid surface or

imperfections caused by the method of manufacturing the filter medium will influence the quantity and kind of ions which are absorbed on the solid surface; this, of course, directly influences the magnitude, and in some instances the sign of the zeta potential. Ives and Gregory (Reference III-4) found that sand washed in a tap water exhibited a zeta potential of -17mV in an environment of $5 \times 10^{-4}$N HCl; however, sand which had been acid washed demonstrated a zeta potential of -27mV.

Many investigators have observed that the streaming potential, and thus the zeta potential, change slowly with time under apparently constant environmental conditions. Although the bulk of these changes are reported to be in the direction of decreasing zeta potentials, increases in zeta potential with time have been also reported (Reference III-3). The cause, or causes, of these time changes has not been identified; however, they are a continuous source of eerors in zeta potential determinations for which no reliable method of compensation has been developed.

Most investigators who have been concerned with the electrokinetic phenomena have assumed that the dielectric constant of the double layer is the same as that for pure water. However, Verwey (Reference III-9) contends that the dielectric constant of the double layer is determined by the ionic species present and should be on the order of two rather than 81 which is the dielectric constant for pure water. Inspection of Equation III-2 shows that the magnitude of the dielectric constant will significantly affect the magnitude of the calculated zeta potential.

Several investigators have noted that streaming potential measurements are often influenced by extraneous potentials which exist or are imparted to the system independently of the electrokinetic potential. Both Agrawal (Reference III-1) and Smith (Reference III-19) observed large potentials across the streaming potential electrodes under no-flow-conditions in their systems. The magnitude of these reference condition potentials can be reduced by careful experimental techniques; particularly in the preparation of the leectrodes. However, the problem is not only the magnitude of the reference potential but also the stability of the reference potential over time.

The numerous sources of error in the experimental techniques associated with electrokinetic measurements indicate that the zeta potentials calculated

from such measurement must be interpreted with caution. Because the zeta potential exhibited by the media is system dependent the implications of the zeta potential of different media cannot be meaningfully compared if the experimental conditions are not similar. However, zeta potentials measured under similar physio-chemical conditions can be used to indicate the relative magnitude of electrical surface forces for different solid-liquid interface conditions. The experimental and analytical errors associated with streaming potential measurements minimize the value of using the calculated zeta potentials to estimate quantitatively the force between charged particles.

The evaluation of the influence of electrical forces on the behavior of solids separation is usually based on the zeta potential values of the media and suspended particles. The contribution of forces of strictly electrokinetic origin to the transport and attachment of particles has not been extensively investigated. Agrawal (Reference III-1) has attempted to develop a quantitative expression between the total electrokinetic forces acting on a particle in the presence of collector grains in a granular media water filter. The basic premise in the development of this expression is that the net electrokinetic force on a particle will be inversely proportional to the square of the distance between the suspended particle and a collector grain. This assumption has not been verified. Agrawal (Reference III-1) has also developed a mathematical expression which suggests that electrokinetic forces may contribute to particle removal to a significantly greater degree than other mechanisms which have been traditionally considered. In addition to the preceding assumption this latter expression is also dependent on the assumption that electrokinetic forces are due to the streaming potential, not the zeta potential, and the shearing of the double layer around the suspended particles. The expression relates the filtration coefficient, $\lambda_o$, to an electrokinetic parameter which is proportional to the zeta potential of the media and that of the suspended particle.

The above analytical approach indicates that removal efficiency can be improved if the media and the particle have zeta potentials of opposite signs. Inasmuch as Agrawal (Reference III-1) has implicitly treated electrokinetic forces as a transport mechanism the substance of his approach is dependent on the applicability of the assumption that the force on the particle is

inversely proportional to the square of distance between media and particle. The impact of electrokinetic forces on the attachment step has not been delineated; nor has the applicability of this concept to the microscreen been considered.

Chemical Forces

Most investigations of filtration phenomena have tended to ignore the importance of chemical forces which result from surface interactions such as; ion exchange, hydrogen bonding, and the formation of coordinate bonds and linkages. These interactions are not expected to have any significant influence on the filtration of discrete particles in the absence of chemical coagulations. However if inorganic or organic coagulants such as alum, iron, or polyelectrolytes are present in, or added to, the influent water then chemical interactions may be significant in attaining particle removal. The chemical forces resulting from theses chemical interactions have not been definitely identified; nor have any attempts been made to quantitatively assess the effects of the chemical forces on the filtration operation. Therefore, the following considerations are only qualitative in character.

Hydrphobic colloidal particles can be coagulated by adding metallic ions, usually aluminum or iron, to the dispersion. Coagulation is accomplished by reducing the repulsive forces between the particles until the attractive forces dominate the system and the particles coagulate. The mechanisms bringing about coagulation are related to changes which can be attained in the Nernst, Stern, and zeta potentials by manipulation of the hydro-chemical environment. However, the destabilization of colloidally dispersed solids by polyelectrolytes cannot be explained entirely by the double layer and other concepts utilized to explain the behavior of hydrophobic colloids. La Mer and co-workers (Reference III-11) and others have interpreted this latter type of colloidal destabilization as a process of adsorption of polymers on the surface of colloids followed by the bridging of the polymer chains between colloidal particles. Stumm and Morgan (Reference III-12) suggest that this same phenomenon may occur when inorganic chemicals are used as coagulants. Ionic forms of aluminum and iron when placed in an aqueous environment form hydroxo metal complexes which behave in a manner similar to the organic polyelectrolytes.

It has been hypothesized that the bridging phenomenon occuring in flocculation may also develop in granular bed water filtration when organic polymers or polyelectrolytes are present (Reference III-12). In this latter instance, the bridging is anticipated to occur between suspended particles and the media grains or particles which were attached to the media grains during a prior bridging process. The dose of polyelectrolyte is critical because an excessive dose will saturate the adsorption sites on the particle and/or media and thus eliminate the possibility of bridging polymers adsorbing on either the media or particles or both.

O'Melia and Crapps (Reference III-13) have shown that the use of cationic polyelectrolytes can reverse the zeta potential of the particles; thus eliminating electrostatic repulsion and enhancing particle attachment. They also note that non-ionic and anionic polyelectrolytes can be nearly as effective in enhancing particle removal as cationic polyelectrolytes; even though charge reversal on the particles does not occur. These results indicate that electrostatic or electrokinetic forces cannot explain observed changes in filter efficiency when polyelectrolytes are added to the influent water. The presence of specific chemical forces which promote particle bonding to the media is strongly suggested by the work of these investigators.

Because the chemical interactions discussed above occur only at the solid-liquid interface it is unlikely that chemical forces contribute to the transport step in filtration. However, if bridging occurs across the interstitial spaces in the media or if only a portion of a polymer is adsorbed on either the particle or media grain then an apparent increase in the rate of transport would be observed as a result of the increase in collector surface. Chemical forces will be most important in the attachment step. A partially coated colloidal particle which comes in contact with a filter surface may have a greater likelihood of being attached due to the numerous charge sites on the polyelectrolyte. The energy barrier to attachment may decrease because of the relative ease with which polyelectrolytes adsorb on solid surfaces.

As an alternative to adding polyelectrolytes to the filter influent to improve filter performance, it has been suggested that the media be pretreated with certain dose of polyelectrolytes preceding filtration.

Agrawal (Reference III-1), Hunter and Alexander (Reference III-14), and several British investigators have noted that this procedure gives improved filter efficiency and allows higher flow rates. Improved removals have been observed using cationic, anionic, and non-ionic polyelectrolytes as was the case for polyelectrolyte addition to the influent water. This again indicates that forces other than electrostatic or electrolkinetic interactions are responsible for particle attachement.

Evaluation of Mechanisms

Two different methods have been used to define quantitatively granular bed filtration performance. The stochastic approach is based entirely on empirical observations and attempts to relate observed filtration performance to suitable parameters in the system. This approach makes no implications about removal mechanisms, and has been shown to be of limited application. The deterministic approach attempts to predict filtration performance by analyzing the underlying mechanisms of removal at a microscopic level. This approach has been hindered by the lack of differentiation between mechanisms involved in the transport and attachment steps of filtration, and by the lack of general agreement on which physio-chemical parameters should be measured. Presently, neither approach has led to the development of methods to predict *a priori* the filtration performance of a given system without recourse to extensive experimental testing.

The postulated mechanisms of particle removal have been briefly discussed and analyzed. These include mechanical straining, gravity settling, interception, impaction, Brownian diffusion, molecular forces, electrostatic forces, electrokinetic forces, and chemical forces. It has been shown that no data or theoretical analyses presently available indicate that one mechanism is universally responsible for particle removal. Furthermore, it is not yet possible to show quantitatively which mechanism may be controlling in the transport and attachment steps under any given set of conditions.

It must again be emphasized that the phenomenon of filtration involves at least two and probably three distinct steps, particle transport, particle attachment, and particle removal due to shearing forces. When either of these steps is controlling or limiting filtration performance, efficiency cannot be improved by enhancing the other steps. For example Agrawal

(Reference III-1) and O'Melia and Crapps (Reference III-13) have shown experimentally that the addition of multivalent ions to the filter can improve filtration efficiency. However, further improvements of filter performance could not be achieved by increased additions of electrolytes, indicating that perhaps the attachment mechanisms were no longer controlling and particle transport was limiting.

It is not usually apparent which removal step is controlling, nor are the controlling mechanisms of these steps easily discernible. Perhaps the most significant unknown factor in predicting filter or microscreen performance is the role of specific chemical forces present when polyelectrolytes or inorganic polymers are present. The magnitude of these chemical forces has not yet been determined, but it appears likely that they may be more important than other surface forces which have been discussed.

Mechanism for Microscreen Model

In the present study it has been necessary to draw upon the existing technical base of the filtration process to establish a basis for selecting a solids removal mechanism for the microscreen model. Two approaches, the stochastic and the deterministic, can also be considered for quantitative definition of microscreen performance, as with granular bed performance. Within the analogy that exists between microscreening and filtration, the stochastic approach has not found much application because of the inconsistency of methology and techniques used for evaluating microscreen experiments. The basic information required for hypothesizing and testing stochastic relationships is simply unavailable.

The deterministic approach leads one to an examination of mechanisms available for predicting performance. At present there exists no firm basis for determining the relative importance of the several mechanisms effecting removal in any given situation as they effect the overall performance of the microscreen. There is a paucity of information with which to establish a uniformity on the definition of the physio-chemical environment required to document the mechanisms. In the absence of firm information, and because of the fundamental development of the microscreen as a screening process, it is proposed that the mechanism of mechanical screening be used to establish a deterministic basis for modelling the microscreen process. Through initial evaluation of published data

followed by laboratory and field inquiry later in the study, the deterministic model using the screening mechanism will be calibrated and adjusted as necessary to reflect the impact of the other mechanisms on process performance. The mechanism of mechanical screening can be documented by particle size distribution data on the influent and effluent streams in the process. It is anticipated that several parameters will affect particle size distributions, including pretreatment, shear, compression, and effective pore diameter of the media and cake, but that the impact of these parameters can be identified and documented in the later programs.

## HYDRAULIC MECHANISMS

### Background

Hydrodynamic phenomena in the microscreen process provide the continuity between the elements of the process, and are the continuous medium in which the transfer of energy and momentum occur. The basic physical properties of liquids are specific gravity, compressibility, and viscosity. Liquids exhibit the phenomena of surface tension at liquid-gas and liquid-solids interfaces as a result of intermolecular adhesive and cohesive forces, and *compression stress* or pressure at liquid-solid interfaces. The flow of a real fluid is a complex phenomenon because of the action of molecular and macro-level forces effecting momentum transfer in the fluid.

The role of hydrodynamics has not been well defined in the microscreening process. Hydrodynamic mechanisms are operative in the following transport functions of the process:

(1) Effecting mixing in both the drum pool inside the screen and the clear well outside the screen.

(2) Generating shear fields as the liquid stream approaches and exits from the surface of the screen.

(3) Generating a boundary layer system on either side of the screen.

(4) Effecting flow through the porous media.

(5) Effecting solids removal from the fabric in the backwash function.

To date the investigative effort has been directed solely to consideration of flow through porous media. Investigators have generally assumed that the laminar flow regime is obtained in liquid flow through both the cake and the screen fabric. There have been no detailed studies of the flow regime through pores of the cake and fabric, although Ives (Reference III-15) and Bowen (Reference III-16) have presented general discussions of the hydraulics of screening which provide background for the presentation below.

Flow Through Porous Media

The microscreen fabric is a porous medium characterized by type of substrate material, aperture size and number, weave type (implying the tortuousity imposed on flow), physical characteristics (yield, flexibility, etc.), and chemical characteristics (resistance to acid, alkali, etc.). The hydrodynamics affecting a discrete section of microscreen can be depicted as follows:

(1) As the segment is immersed in the liquid pool, liquid (driven by the constant head differential between the drum pool and clear well) flows into, through, and out of the screen, transporting solids to the surface of the media at which discrete particles are trapped.

(2) As the segment progresses through the liquid pool, progressive layers of particles are deposited on the fabric, forming ( at the incremental level) layers of particles through which the flow must traverse before it passes the fabric. With progression of the segment through the fabric, the length of channel which the flow must traverse increases, and the pore size (or trapping diameter) becomes a function of the character (packing, porosity, etc.) of the cake. If it is assumed that the differential head remains at a constant value while the resistance to flow through the *filter medium* (combination of cake and fabric) increases, then the flow rate through each increment will decrease.

Within the above framework, several approaches have been proposed for description of the flow through the *filter medium* on the assumption that laminar flow obtained. Ives (Reference III-15) treated the pores as capillaries of constant diameter and porosity, and used the Poisseuille law to predict headloss. Roessler (Reference III-17) used Darcy's Law

in his microscreen model to predict the total headloss as two components: headloss across the screen fabric; and headloss across the filter cake. Mixon (Reference III-18) used Darcy's Law in his model; the clean screen headloss factor in Boucher's Filterability Index is also calculated using Darcy's Law. Thus, the two basic laws for flow through porous media (Darcy's Law and Poisseuille's Law) have been considered in the prediction of headloss behavior in the microscreen process.

## PARTICLE SHEAR

### Background

Particles can be described as either discrete or aggregate as a function of how they were formed. Many of the types of particles found in water and wastewater are discrete (such as a fragment of wood) whereas processes such as chemical or biological flocculation produce aggregate particles. The strength of the particle can be defined as its ability to withstand shearing stresses imposed on it in a shear field such as is believed to be generated with the flow of liquid through the microscreen process. Based on the limited body of information in the literature (summarized in Reference III-19), the major consideration of particle shear has been with aggregate rather than discrete particles. The emphasis in subsequent discussion is placed on floc strength of particle aggregates (flocs) produced in the chemical pre-treatment of aqueous streams, but; because of the aggregate nature of biolcgical floc, is applicable in a general sense to all aggregate particles.

### Significance of Floc Strength

Flocs formed by the addition of coagulants to an aqueous system are the result of a complex series of events, both physical and chemical, which involve the properties of the solvent (water), the solute (ions, organic materials, colloids, and particulates), and the coagulant. Initial floc formation (primary floc) is primarily a chemical phenomenon, which consists of charge neutralization and aggregation through collisions brought about by Brownian motion. Brownian motion is a dominant mechanism for aggregation until the flocs reach a size of approximately 0.1 micron. Thereafter, velocity gradients generated by mixing devices or other means

of energy input effect further collisions between the primary flocs, causing the formation of larger aggregates designated as secondary flocs (Reference III-20).

The bonding forces within the primary flocs are considered to be stronger than the bonding forces between the primary flocs. When the applied shear stress is greater than the cohesive force of an aggregate floc, the floc will be fragmented into the smaller sizes. The practical upper size limit for coagulant flocs in water treatment facilities is in the range of 100 to 2,000 microns (Reference III-21), and for a given situation this upper limit is determined by the cohesive forces between primary flocs making up the secondary floc and shearing stresses imposed on the floc by velocity gradients in the fluid medium.

The floc strength can be defined as the ability of an aggregate or secondary floc to withstand shearing stresses (which may be applied during both flocculation and solids removal operations). By knowing the shear stress applied and the sizes of fragmented flocs, it is possible to estimate the effective cohesive forces within the aggregate flocs. Therefore, floc strength can be quantitated for any system.

Effect of Floc Strength in Filtration Processes

Two factors are of major concern in the operation of filtration-type processes. The first concerns the efficiency of particle removal in a unit area or volume of media while the second is the headloss limitation.

In consideration of the first aspect, the attachment of floc to filter media is due to the transport of flocs near to the media where they are attached either to the media or to the floc already attached. Because strong floc implies a strong cohesive force, the efficiency of attachment to media is expected to be greater for the stronger flocs than for the weaker flocs. On the other hand, strong floc can resist shearing forces much better than weaker floc and may tend to plug the filter media leading to cake formation and filtration. For the weaker floc the efficiency of attachment may be lower but the weaker floc tends to be broken down when the interstitial velocity of the liquid increases, and the floc will be

moved down to a lower level in the cake. Consequently, the weaker floc may serve to maintain pore openings much better than the stronger floc.

Cake filtration results in greater headloss than depth filtration and in those cases where a limited hydraulic head is available, it may be desirable to have weak flocs. On the other hand, weak flocs are undesirable from the standpoint of removal efficiency. From these two opposing considerations it has been suggested that an optimum floc strength may be found at some value which gives moderate removal efficiency and moderate headloss rate (Reference III-19). The selection of the optimum floc strength for a given condition of solids separation will be a function of the specific objectives for that separation.

Particle Shear in Microscreen Process

Particle shear is believed to have a much greater likelihood of occuring in the microscreen process than in the rapid sand filtration process for two major reasons:

(1) The interstitial flow rate in the microscreen process is typically in the order of five to 10 gpm/sq ft as compared with two to five gpm/sq ft in the rapid sand filtration process.

(2) Particles traversing the liquid pool in the drum are subjected to shear forces generated as the rotation of the drum imparts motion to the liquid contiguous to the drum; no similar opportunity for *shear on approach* exists in the conventional rapid sand filter design. It is unknown what effects these factors have on the total question of particle shear in the microscreen process. Nor has the effect of particle shear on performance of the rapid sand filter been defined or even considered at the prototype level. At the present time it can only be hypothesized that particle shear is an important factor in the performance of the microscreen process. It can also be hypothesized that an optimum floc strength can be defined for the operation of the microscreen to meet operating objectives for solids removal. The question of particle shear and its impact on the microscreen process will be considered in the field program.

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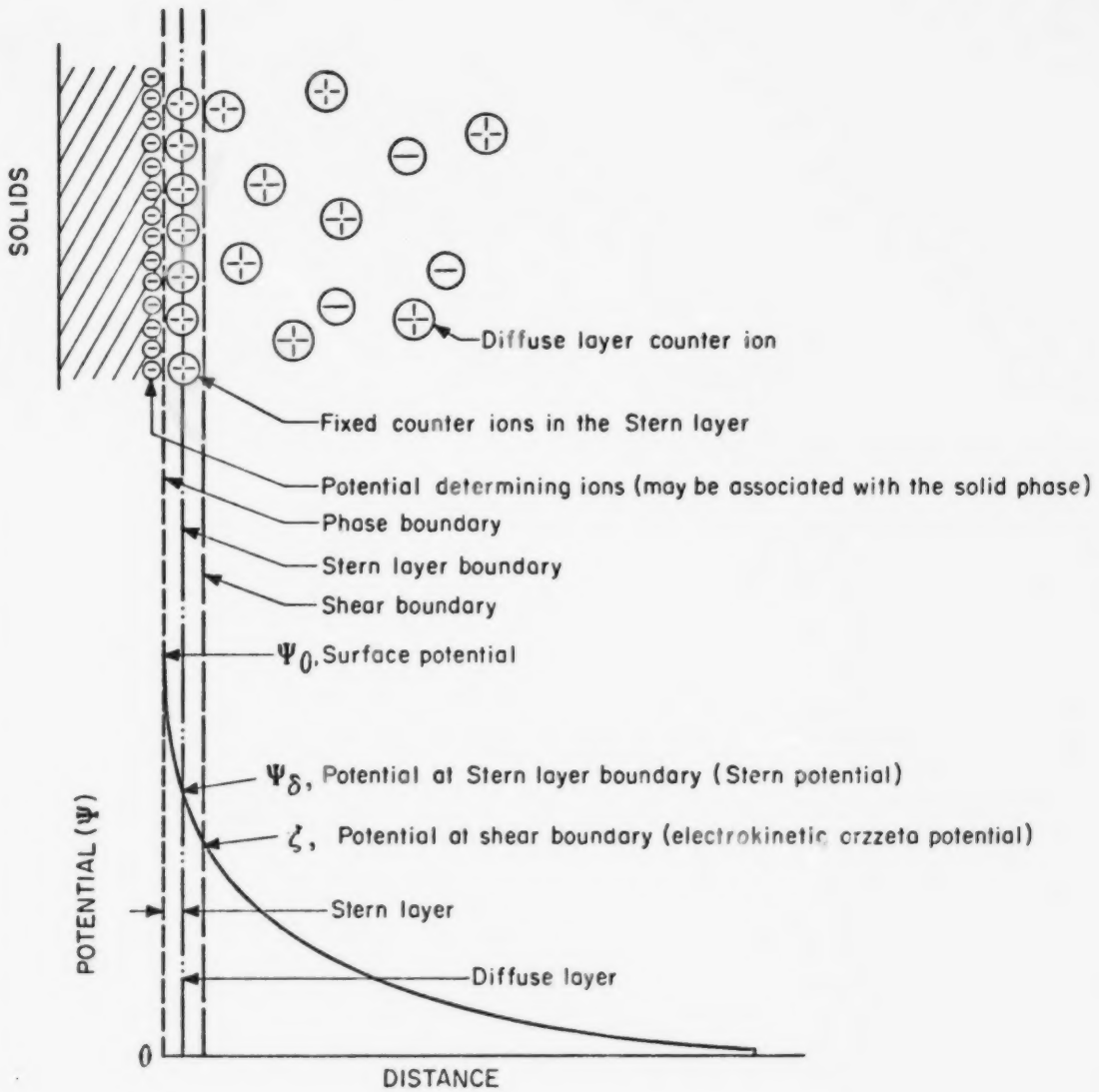
# VARIATION OF POTENTIAL IN AN ELECTRICAL DOUBLE LAYER (According to Stern's Theory)



# CHAPTER IV

# MICROSCREEN DESIGN AND PERFORMANCE

## PROCESS APPLICATIONS

Microscreens were first used for the removal of algae in water treatment systems to extend the runs and improve the performance of sand filters. As the technology for production of media improved, and finer mesh screens became available, the process came into use as the sole separation treatment device for waters where colloidal turbidity is absent. Microscreening has been used downstream of sand filters, after storage of purified water, and for the recovery of washwater, and in industrial water treatment applications such as reconditioning of air conditioning system water, cooling system water, fish hatchery tray water, and fiber and solids recovery. Microscreening experience for conditioning raw water in municipal facilities and raw and recycled water in industrial applications is reported in References IV-1 to IV-7.

Microscreening has also been used for the tertiary treatment of settled and unsettled trickling filter effluents, settled activated sludge process effluents, and oxidation pond effluents. References IV-4 and IV-6 to IV-21 summarize experience with microscreens in the tertiary treatment of these effluents. A significant body of experience with the microscreen has evolved in industrial wastewater treatment (Reference IV-7), examples of which follow:

(1) Filtering solids from plant effluents in vegetable and citrus canneries, beef slaughterhouses and horse meat plants, and poultry plants.

(2) Dewatering large fleshings and reclaiming fine hair from tanning plant operations.

(3) Screening out wet granulated slag from blast furnaces in steel mills.

(4) Separating hulls and foreign particles in malting plant operations.

Unfortunately, a similar base of experience has not developed in application of the microscreen process to raw or primary-treated municipal wastewaters. Christman (Reference IV-2) has referred to the use of microscreens in the primary treatment stage of a municipal waste treatment facility instead of settling tanks, and Diaper (Reference IV-22) has referred to the use of microscreens for treatment of combined sewer overflows in Philadelphia.

## DESIGN CONSIDERATIONS

### Objectives and Criteria

The systems context for the microscreen process as presented in Chapter II can also be viewed from a design perspective. The objectives of the designer have related to identification of the desired liquid throughput rate and permissible headloss. The remaining process definition, i.e., selection of screen size, backwash capacity, surface area, etc., are traditionally assigned to the manufacturer by the design engineer. Inasmuch as much of the information required for design of the microscreen is proprietary, the designer has little alternative but to rely on the manufacturer. As a result, the tradition has arisen that the designer *per se* has had very little concern for a basic knowledge of the fundamentals of the process, i.e., for a knowledge of what affects solids retention, choice of screen, etc. The effect of this tradition has been that there exists no generally available body of information defining for the designer the general criteria he needs to fulfill his mission. The effects of these circumstances are as follows:

(1) The basic information on how to design microscreen is resident not in the designer, but in the manufacturer.

(2) Each installation of the microscreen has been viewed as a unique application of the process rather than an extension of process utility in a general framework.

(3) There is little patent evidence available that the microscreen has been used traditionally with the specific objective of maximizing solids removal, the overtly-stated mission for the existence of the process.

## Fundamental Considerations

The two primary design considerations in the application of microscreens have been the hydraulics, which determines the relative capacity of an installation, and the solids removal efficiency. Hydraulic capacity has been the principal design determinant, with practical limits arising from headlosses, approach velocity, and physical strength of the fabric to support differential heads. The solids removal efficiency is a function of the particle size distribution, character of solids, nature of cake formed, and solids retention effected by the filter medium.

### Hydraulics

Boucher (Reference IV-3) has developed a general equation for prediction of headlosses through microscreens. According to his concept for filtration through screens where cakes are formed, the process is characterized by a basic headloss (clean-screen headloss for a given flow velocity) plus progressive losses from the continuing accumulation of debris on the screen. Boucher's formulation, based on studies in natural waters, has been found to describe process behavior below conditions causing a breakdown of the mat. At the latter point the rate of increase of headloss changes with respect to volume filtered.

According to Boucher, headloss at any stage of the screening cycle, without breakthrough, is the simple sum of the clean screen headloss and additional headlosses due to the accumulation of solids on the screen. The accumulation depends on the cumulative volume of water screened, starting with a clean screen, and the nature of the retained solids.

The Boucher formula is:

$$H_v/H_o = e^{IV} \qquad \text{(IV-1)}$$

where: $H_o$ = headloss at a constant flow rate through the clean screen

$H_v$ = headloss at a constant flow rate after the passage of a volume of liquid V through the screen at the constant flow rate.

$I$ = filterability index ($L^{-1}$)

$V$ = cumulative total filtrate volume per unit area ($L$)

Clean screen headloss can be related to flow by the equation,

$$H_o = C_f \times v \qquad \text{(IV-2)}$$

where: $v$ = velocity ($LT^{-1}$)

$C_f$ = clean screen factor (T)

The clean screen factor is a constant if the velocity of flow corresponds to Reynold's Numbers less than about 100 (based on velocity and wetter perimeter of the actual unit aperture), Reference IV-23. When Reynold's Number exceeds 100, turbulent flow obtains and $H_o$ is proportional to $v^2$.

Boucher's approach has been applied to rotary screen through the use of the following equation (Reference IV-17):

$$H = \frac{m\, Q\, C_f\, e^{nIQ/S}}{A} \qquad \text{(IV-3)}$$

where: $H$ = loss of head across the strainer (L)

$Q$ = constant total rate of flow through the unit ($L^3/T$)

$A$ = effective submerged area of the screen

$S$ = speed of the strainer (number of units of area of effective fabric entering water in a given time ($L^2/T$)

$m$ and $n$ = conversion factors; for H in inches, $C_f$ in feet, A in sq ft, S in sq ft per minute, m and n have values of 0.0267 and 0.1337 respectively

$C_f$ and $I$ = as defined above

The foremost assumption of the above equation is that headloss is a function of the constant total flow rate. This assumption is tenuous at best because of the non-linear distribution of flow velocities across a screen at any point in the screening cycle; at best it would appear necessary to provide a correction factor to Equation IV-3 to account for the anomaly.

The concept of a Filterability Index (I) has been the principal source of confusion in the use of the above equation. This confusion arises in part because I is reported to be a variable parameter even when the solids are derived from the same source. There exists no

published information relating I with parameters characterizing solids character, solids retention, or filter medium. In the absence of such a correlative base, information gained on I in studies with one water have not been transferrable to another case. Consequently, I has not become a widely understood or useful parameter.

Solids Removal Efficiency

The types of design criteria used explicitly or implicitly with respect to solids removal efficiency include solids character, screen size, Filterability Index, peripheral speed of screen and headloss. Solids can be characterized as (Reference IV-23):

(1) General Debris: inorganic particulate from 10 to 100μ in size and organic particulate matter mostly derived from dead flora or fauna or from their excretion and in the 10 to 100μ size range.

(2) Microorganisms: algae, fungi, bacteria, protozoa, metazoa, etc. The solids removal efficiency depends primarily on the location in the screening cycle at which a sufficient base of larger particles has been deposited to effect, in turn, a capture of the final solids.

The point of *onset* of a *threshhold cake formation* level is a function of the combination of screen size, particle size distribution, and source, and operating variables used in the specific application of the process. To date, essentially no information exists from which to correlate the above factors and to rationalize design relationships for solids removal efficiency. The available information on factors such as $C_f$ and I has point applicability only.

Available information on reported $C_f$ and I values for various microscreen applications is summarized in Table IV-1. The cited applications apply generally to one of two possible objectives; for preparation of raw waters for water treatment,and for polishing of unsettled and settled trickling filter effluents and settled activated sludge effluents. The following trends can be noted from Table IV-1:

(1) The Filterability Index of secondary effluents (say 5 to 50 $ft^{-1}$) is two orders of magnitude greater than those of the raw water sources (say 0.2 to 1.2 $ft^{-1}$) for the same screen size (23μ nominal aperture).

TABLE IV-1

PUBLISHED DATA ON DESIGN CRITERIA FOR MICROSCREENING OF RAW WATERS AND SECONDARY EFFLUENTS

| Source or Form of Wastewater | Treatment Objective | Fabric Tested | | Filtrability Indes (I) (mean and range, $ft^{-1}$) | Clean Screen Factor (Inches) | Reference |
|---|---|---|---|---|---|---|
| | | Type | Norminal Aperture (μ) | | | |
| Reservoir at Depth | Preparation for Water Treatment | SS | 35 | 0.087 | | IV-23 |
| Reservoir at Surface | Preparation for Water Treatment | SS | 35 | 0.110 | | IV-23 |
| Canal Stream | Preparation for Water Treatment | SS | 35 | 0.085 | | IV-23 |
| Reservoir at Depth | Preparation for Water Treatment | SS | 23 | 0.37 | | IV-23 |
| Reservoir at Surface | Preparation for Water Treatment | SS | 23 | 0.34 | | IV-23 |
| Canal Stream | Preparation for Water Treatment | SS | 23 | 0.45 | | IV-23 |
| Open Canal Stream | Preparation for Water Treatment | SS | 640 | 0.0003 | | IV-23 |
| Open Canal Stream | Preparation for Water Treatment | SS | 335 | 0.04 (0.044-0.021) | | IV-23 |
| Open Canal Stream | Preparation for Water Treatment | SS | 185 | 0.076 (0.100-0.045) | | IV-23 |
| Open Canal Stream | Preparation for Water Treatment | SS | 110 | 0.081 (0.120-0.058) | | IV-23 |

TABLE IV-1 (Cont'd)

| Source or Form of Wastewater | Treatment Objective | Fabric Tested | | Filtrability Index (I) (mean and range, $ft^{-1}$) | Clean Screen Factor (Inches) | Reference |
|---|---|---|---|---|---|---|
| | | Type | Norminal Aperture (μ) | | | |
| Open Canal Stream | Preparation for Water Treatment | SS | 65 | 0.189 (0.535-0.109) | | IV-23 |
| Open Canal Stream | Preparation for Water Treatment | SS | 35 | 0.58 (0.58-0.11) | | IV-23 |
| Open Canal Stream | Preparation for Water Treatment | SS | 23 | 1.19 (2.40-0.48) | | IV-23 |
| Activated Sludge Effluent | Effluent Polishing | SS | 23 | 15.6 (25.2-10.4) | | IV-8 |
| Activated Sludge Effluent | Effluent Polishing | SS | 35 | 4.98 (9.30-1.71) | | IV-8 |
| Activated Sludge Effluent | Effluent Polishing | SS | 35 | 17 (27-4) | 12.0 | IV-17 |
| Activated Sludge Effluent | Effluent Polishing | SS | 23 | 17 (26-8) | 21.6 | IV-17 |
| Trickling Filter Effluent (Unsettled) | Effluent Polishing | SS | 35 | - (60-10) | | IV-19 |

(2) The Filterability Index for the same raw water increased from 0.0003 $ft^{-1}$ with a 640μ screen to 1.19 $ft^{-1}$ with a 23μ screen.

(3) Clean screen factor varied from 12 inches (at an approach velocity of one fps) in a 23μ screen to 21.6 inches in a 35μ screen.

Two research groups have attempted general correlations between the Filterability Index I and operating parameters. Bodien and Stenburg (Reference IV-17) observed a correlation between influent suspended solids and I in pilot studies with secondary effluents at Lebanon, Ohio. Two screens were considered (23μ and 35μ nominal aperture sizes) and coincidentally the same correlation equation was found for each, i.e.,

$$I = 0.494\ X_o^s \qquad \text{(IV-4)}$$

where: I = Filterability Index ($ft^{-1}$)

$X_o^s$ = influent suspended solids concentration (mg/l)

The best correlation was obtained with the 23μ fabric, and the researchers held the opinion that factors causing the scatter include variation of the particle size distribtuion in the influent stream.

Truesdale *et al* (Reference IV-19) presented correlations between Filterability Index, flow rate, and influent solids levels. The observations were made with the microscreen performing at a constant headloss setting of six inches ± one inch and a constant rate of screen presentation of 47 fpm. Though the data were well scattered, there is an indication that the maximum flow rate increased as the Filterability Index decreased below 30. There is also an indication that I increased with increasing influent suspended solids concentration, although the data were not reproduced at the detail necessary to demonstrate the latter case (which was reported above from the work of Bodien and Stenburg, Reference IV-17).

## PERFORMANCE

### Observations

Performance of specific microscreen installations has been tracked various.y by the following types of information:

(1) Liquid Balances: influent and effluent rates; applied backwash rate; and net backwash rate.

(2) Solids Balances: influent and effluent suspended solids concentrations and mass emission rates; washwater (net backwash) suspended solids concentrations and mass emission rates.

(3) Screen Character: nominal aperture size; screen weave and material type.

(4) Screen Loading Rates: solids (mass/unit area/time); and liquid (volume/unit area/time).

(5) Solids Character: nature and source of solids in liquid stream; Filterability Index; solids pretreatment; and particle size distribution.

(6) Other water quality characteristics.

Needless to say, very few of the applications have been described with the totality of information presented above. Foremost attention has been given to the actual liquid throughput rate and influent and effluent suspended solids and BOD levels, primarily to demonstrate for sales purposes the utility of the process. Only two references in the body of literature reviewed (Reference IV-13 and IV-19) reported solids balances in sufficient detail to permit use of the data; only one reference (Reference IV-2) considered the role of particle size distribution in the process.

Typical performance data for microscreens in the treatment of activated sludge and trickling filter effluents are shown in Table IV-2. Specific surface loading rates varied from 6,500 to 13,000 gpd/sq ft (gallons per day per sq ft) of effective (submerged) area for treatment of both types of effluents. Typical removal levels for suspended solids with 23μ screens were 55 to 90 percent for both effluents, and effluent suspended solids and BOD levels less than 10 mg/l were frequently reported. Operating data on backwash operations in microscreening of secondary effluents is shown in Table IV-3. The applied backwash water varied from three to 12 percent of the influent flow rate but the reported *net* backwash rate varied from two to six percent, i.e., from 50 to 60

TABLE IV-2

PERFROMANCE DATA FOR MICROSCREENING

OF SECONDARY EFFLUENTS

| Stream | Nominal Aperture (μ) | Microscreen Capacity (mgd) | Typical = Effective Loading Rate (gpd/sq ft) | Suspended Solids (mg/l) | | | BOD (mg/l) | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Infl. | Effl. | % Reduction | Infl. | Effl. | % Reduction | |
| Act. Sl. Effluent | 23 | 2.0 | 10,000 | - | 4 | 55 to 71 | - | - | 55 to 73 | IV-11 |
| Act. Sl. Effluent | 23 | 0.8 | 6,500 | 17.2 | 6.6 | 60 | 19.2 | 9.5 | 50.5 | IV-13 |
| Act. Sl. Effluent | 23 | 0.07 | 7,000 | - | - | 57 | - | - | 53.5 | IV-8 |
| Act. Sl. Effluent | 23 | 0.086 | 8,500 | 17 | - | 89 | - | - | 81 | IV-16 |
| Act. Sl. Effluent | 35 | 0.097 | 9,500 | 27 | - | 73 | - | - | 61 | IV-16 |
| Tr. Filt. Effl. | 23 | 0.10 to 0.13 | 10,000 to 13,000 | 99 | 26 | 64 | - | - | - | IV-21 |
| Unsettled Tr. Filt. Effluent | 23 | 0.30 | 10,000 | 40 | 11 | 73 | 17 | 10 | 40 | IV-10 |
| Tr. Filt. Effl. | 35 | - | - | 17 | 6 | 67 | 14 | 8 | 42 | IV-10 |
| Unsettled Tr. Filt. Effluent | 35 | - | - | - | - | 86 | - | - | 66 | IV-10 |

TABLE IV-3

OPERATING DATA ON BACKWASH OPERATIONS

FOR MICROSCREENING OF SECONDARY EFFLUENTS

| Stream | Fabric Nominal Aperture (u) | Effective Loading Rate (gpd/sq ft) | Applied Backwash (% Influent) | Backwash Pressure (psi) | Net Backwash (% Influent) | Solids in Backwash (% Influent) | Operating Head Cass (in) | Reference |
|---|---|---|---|---|---|---|---|---|
| Act. Sl. Effluent | 23 | 10,000 | 3 | | | - | - | IV-11 |
| Act. Sl. Effluent | 23 | 5,700 | - | 15 | 5.0 | 70 | 6 | IV-12 |
| | 23 | 7,400 | - | 50 | 1.9 | 60 | 3 | |
| Act. Sl. Effluent | 23 | 8,500 | 11.8 | - | 5.3 | - | 3-1/2 | IV-17 |
| | 35 | 9,500 | 11.1 | - | 5.0 | - | 3-1/2 | IV-17 |
| Tr. Filt. Effl. | 23 | 10,000 to 13,000 | - | 30 | 4.4 | - | 3 4 | IV-21 |
| Unsettled Tr. Filt. Effluent | 23 | 10,000 | 10 | 12 | 5 | - | 6±1 | IV-19 |

percent of the applied backwash water flow rate. Typically, 60 to 70 percent of the suspended solids input was recovered in the net backwash flow. Reported backwash pressures varied from 12 to 50 psi, with pressure being identified invariably as a more important factor than applied backwash flow rate in the cleaning of screens.

## Evaluation of Performance Documentation

### Evaluation

The scope of the above information provides essentially no information for the following elements of the systems context of Figure II-1:

(1) Solids Input Rate: routing of dissolved and colloidal solids into system.

(2) Filter: effect of weave type, material properties, and nominal aperture on effective pore diameter.

(3) Solids Character: nature of the particle size distributions of different types of suspension, shear of particles, and impact of these variables on the Filterability Index.

(4) Solids Retention: nature of the properties of the formed cake.

(5) Filter Medium:

- Effective pore diameter
- Cake character
- Overall headloss character as function of above

(6) Backwash: effect of more efficient backwash on reduction of residual surface density of screen and reduction of initial headloss.

Thus, very little can be said about the characteristics of the microscreen process below the process level. However, given the systems context of Figure II-1, and the random observations in the literature, much can be implied about the composition of the microscreen process.

The first area of implication is the hypothesis in the literature on the role of solids in controlling process behavior. The first hypothesis (Reference IV-11) states that the greater the buildup of the solids loading

rate, the greater will be the removel of particulate matter. The second hypothesis is that a proportionality exists between influent and effluent suspended solids levels. The first hypothesis implies that a relationship exists between solids input rate, solids retention, and filter medium (i.e., between a rate and two levels); as such the hypothesis does not differentiate between a loading factor and a density factor, the latter accounting for particle removal performance and controlled by backwash as well as solid input rate. The hypothesis would be expected to hold if the nature of the particle permitted formation of a cake which could trap fine particles; in the opposite case, screening would be the solids removal mechanism and particle penetration would be expected.

The second hypothesis (proportionality of influent and effluent solids concentration) is also dependent on the nature of solids separation (surface or depth) taking place. The effluent solids concentration is a function of the location in the screening cycle at which particle penetration is stopped as a result of cake formation, i.e., a function of particle size distribution, screen size, particle shear, etc., rather than influent particle size. Thus, it would appear fortuitous if in the general case the second hypothesis were valid.

The second area of implications is the relationship between liquid throughput and solids input rates. The premise of the systems context is that liquid throughput rate is not limited by the solids input rate but rather by the hydraulic characteristics of the filter medium. Observations (Reference IV-11) have indicated that maximum hydraulic loadings can be reached in the operation when the solids input rate is less than the maximum observed, the implication being that factors other than the solids input rate were limiting liquid throughput.

Particle character is a foremost factor implicated in the performance of the microscreen. Solids removal efficiency is reported to increase with increasing particle size, although some agglomerated materials such as mineral, diatoms, and organic debris tend to disperse during microscreening into smaller, non-separable particles (Reference IV-2). The degree of autoflocculation has been reported to affect the filterability of biologically-treated effluents (Reference IV-19). Particle shear has

been identified as a problem factor in some microscreen applications; pumps have been reported to cause the shear of fragile floc (Reference IV-21) and the use of alum coagulation to improve removal of pin-point particles has not been reported to be successfull because of floc shear at the screen (Reference IV-11).

It is apparent from the foregoing commentary that the success of a microscreen application is dependent on the selection of a fabric and operation of the system to develop a solids retention capacity (by screening or cake formation) rapidly enough to maintain low effluent solids emissions while producing a filter medium capable of maintaining an adequate liquid throughput rate.

## MATHEMATICAL MODELS

### Description

Two mathematical models have been proposed for the microscreen process, each of which incorporates the Filterability Index concept in expressions for predicting headloss as a function of specific flow rate. Roessler (Reference IV-24) incorporated an expression of the form of Equation IV-3 into his model, using the following assumption:

(1) The Filterability Index of the suspension can be predicted by the Bodien-Stenburg equation (Equation IV-4).

(2) The cake is noncompressible, of constant density and porosity, and forms linearly on the screen during the screening cycle.

(3) Fluid viscosity is constant

(4) Two components define headloss; one due to the clean screen and the second due to the cake.

The Roessler model incorporates the Filterability Index to generate a transform between the element of solids input rate, solids retention, filter medium, headloss, and backwash in the systems context of Figure II-1.

The second mathematical model was proposed by Mixon (Reference IV-25) and also incorporated the Filterability Index concept. The key feature of the Mixon model is that it incorporates a nonlinear variation of headloss

on the screen as the screening cycle progresses from submergence to emergence. Liquid throughput rate at any point on the screen is defined as a function of the headloss due to specific deposit of screened material at that point plus clean screen headloss. Mixon's analysis showed that estimates of capacity based on the assumption of linearity are about 35 percent less than those predicted by integrating his non-linear relationship over the screening cycle.

Evaluation

Both the Roessler and Mixon model are initial and substantive efforts to establish a deterministic basis for predicting the performance of the microscreen process. However, given the present state of understanding of the process, particularly with respect to the proposed systems context, it would appear that additional empirical-level understandings of the basic input-output of the process is needed before a deterministic approach is warranted. Particularly lacking is definition of the interactions between solids input rate, solids retention, filter medium, headloss, and backwash. There is a need for synthesis of the existing work that has been done into a framework pointing implicitly to where determinism can be used within the reality of existing information. The present information base suggests strongly that solids balances, solids loading, and generic descriptions of the type of cake can be examined both as the basis for expressing empirically the behavior of the microscreen process, and as a departure point for identifying the role and scope of the deterministic model to be developed in the present study.

## CHAPTER IV

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# CHAPTER V
# EMPIRICAL CONCEPT FOR MICROSCREEN PROCESS

## REQUIREMENTS

An empirical concept of the microscreen process is needed at this point to provide a link between the stochastic observations prevalent in the literature and the systems context for the process presented in Chapter II. The basic premise of the empirical concept is that it can be based only an a synthesis of available information, which as discussed in Chapter IV relates indirectly to some of the elements of the context (solids character, filler, and solids input rate), and not at all to the elements of solids retention and filter medium. The empirical concept thus developed can serve as the basis for rationalizing with respect to identifying which elements in the systems context can be considered in the deterministic microscreen model for the study.

The scope of the existing information base, while limited, permits the following to be documented for specific microscreen applications reported in the literature:

(1) Liquid and suspended solids balance and suspended solids loading factors.

(2) Effect of fabric characteristics of nominal aperture size on solids removal.

(3) Effect of headloss and backwash efficiency on liquid and solids balances.

On the above basis it was assumed also that the empirical concept should be required to integrate the information into relationships between:

(1) Liquid and solids loading factors and solids removal efficiency.

(2) Effect of nature (source) of solids on the solids removal efficiency.

(3) Effect of fabric aperture on solid removal efficiency.

## DEVELOPMENT

### Basic Relationships

The initial premise in formulating an empirical concept was the hypothesis from the literature that solids removal efficiency could be related to a solids loading rate. The implication of this premise relative to the systems context is that an increase in a solids loading factor would affect the solids retention and filter medium in a manner which reduces particle penetration and increases effluent quality by decreasing effluent suspended solids concentrations. The solids loading factor relating implicitly to solids retention would necessarily consider the following parameters: solids input rate, rate of screen presentation; and screen area. A solids loading factor, S/R, incorporating the above parameters, was formulated as follows:

$$\frac{R}{S} = \frac{q\ DL\ \pi\ X_o^s}{DL\pi\omega} \quad \text{or} \quad \frac{q\ X_o^s}{\omega} \qquad \text{(V-1)}$$

where: S = Solids input rate, lb suspended solids per day

R = Rate of screen presentation, sq ft per day

q = Specific liquid throughput rate, gallons per sq ft of screen per day.

D = Screen drum diameter, ft

L = Screen width, ft.

$\omega$ = Rate of drum rotation, rev/min.

$X_o^s$ = Influent solids concentrations, mg/l

The S/R factor has units of lb/sq ft, and represents the average suspended solids load imposed on a unit area of fabric. The S/R factor can increase as liquid throuput or solids input rates increase or as rate of drum rotation decreases, and can be used as a design factor.

Background information on variation of microscreen solids removal efficiency with a solids loading factor (Reference V-1) indicated that as S/R increases, the solids removal efficiency would increase at a gradually decreasing rate to a point where no further efficiency could be achieved by increasing S/R, i.e., a retardant form of equation should be used to

relate S/R and solids removal efficiency as measured by the ratio of effluent suspended solids ($X_o^s/X_I^s$). The general form of the retardant equation used for considering the existing data is:

$$\frac{X_I^s}{X_o^s} = \frac{1}{1 + a(S/R)^n} \qquad \text{(V-2)}$$

where: $X_I^s$ = effluent suspended solids concentration, mg/l
$X_o^s$ = influent suspended solids concentration, mg/l
a = system constant
n = system constant

The constants a and n were included to consider the effect which the nature of a type of solids being removed would have on improving or reducing the parameter $X_I^s/X_o^s$ at a given S/R value. That is, the a and n terms were assumed to be constant values for specific types of solids, and to vary between types of solids as a function of:

(1) The controlling class of mechanism in the separation, i.e., surface (screening) vs. depth (cake) removal of particles.

(2) The degree of particle penetration permitted by the filter medium generated with the specific type of retained solids and specific fabric.

Equation V-2 can be linearized in the following form for determination of the constants a and n.

$$\log [(X_o^s/X_I^s) - 1] = -n \log (R/S) + \log a \qquad \text{(V-3)}$$

The second premise in formulating the empirical concept was that a relationship could be established between a normalized hydraulic loading parameter and the solids loading factor. The normalized parameter was defined in units of gph/sq ft/mg/l influent suspended solids (i.e., $q/X_o^s$), which represents a hydraulic design factor. The assumption in the relationship incorporating this factor was that the level of $q/X_o^s$ would decrease to a minimum level as S/R increased. The following retardant equation form was selected for initial inquiry:

$$\frac{q}{X_o^s} = \frac{b}{c + (S/R)} \qquad \text{(V-4)}$$

where: b and c are constants relating implicitly to the controlling class of mechanism (surface or depth) effecting solids separation and the headloss character of the filter medium.

Equation V-4 can be linearized in the following form for the determination of the constants b and c:

$$\frac{X_o^s}{q} = \frac{c}{b} + \frac{(S/R)}{b} \qquad \text{(V-5)}$$

Source Data

Two sets of data were available in the literature for evaluating the constants of Equations V-2 and V-4; both data sets were developed in studies in the United Kingdom by Truesdale *et al*, (References V-2 and V-3). Truesdale's initial study was done at Harpenden Sewage Works with unsettled trickling filter effluents in 1962-63, and his second study was done at Letchworth Water Pollution Control Works with clarified activated sludge effluents in 1966-67. In both cases the same five feet diameter by three feet wide Glenfield and Kennedy Microstrainer was used; a 35μ (Mark 1) fabric was used with the trickling filter effluent, and a 23μ (Mark 0) fabric was used with the activated sludge effluents. The microscreen unit in both studies was generally operated at a headloss level of six inches ± one inch and a rate of rotation of about three rev/min; the liquid throughput rate was the maximum value that could pass through the machine under these operating conditions and the salient influent suspended solids concentration. Midway through the 1966-67 studies at Letchworth, the backwash jets on the microscreen were changed, permitting the pressure of water applied to the jets to be increased from 15 to 50 psi, and headloss to be reduced to about three inches.

Truesdale, *et al* reported no information describing either the particle size distribution or the generic character of the activated

sludge and trickling filter solids in the streams studied. Tchobanoglous (Reference V-4) reported the results of a particle size determination on a settled activated sludge effluent which indicated that these particles fell into two distinct size ranges, i.e., the distribution was bimodal. The smaller particles varied in equivalent circular diameter from 1μ to 15μ (mean size 3 to 5μ) while the larger size range varied in size from 50 to 180μ (mean size 80 or 90μ). In addition, a few particles greater than 500μ were almost always found. All the particles were found to be light and amorphous and did not settle readily. It was estimated that the weight fraction of the smaller particles was approximately 40 to 60 percent of the total.

Similar detailed information on particle size distribution was not found for unsettled trickling filter effluents. The solids in trickling filter effluents are comprised of the sloughings of the basic slime layers on trickling filter media as well as wastewater colloidal and suspended solids passing unmodified or partially modified through the filter. The basic slime layer on trickling filter stone is composed of a complex of microscopic organisms including bacteria, fungi, algae, and protozoans (Reference V-5). Of these organisms, the fungi and algae comprise most of the attached material, and under conditions of high liquid loading or over production of slime components, the growths slough, with the release of sludge mats and (as reported variously) large numbers of worms. Thus, it would appear that unsettled trickling filter effluents are characterized by a greater predominance of bulkier particles than are found in activated sludge effluents.

Evaluation of Constants

The basic data developed in the Harpenden and Letchworth studies as well as calculated parameters for evaluation of the constants in Equations V-2 and V-4 are presented in Tables A-1 and A-2 of Appendix A. The parameters $[X_o^s/X_1^s - 1]$ vs. R/S are plotted in Figure V-2 for the Letchworth Studies with 50 psi backwash pressure. In all figures the orientation of the data confirms the proposed relationships over one-half to one order of magnitude of variation of the parameters. The constants obtained for the linearized form of Equation V-2 were as follows (with

S/R in units of lb/sq ft):

(1) Harpenden (unsettled trickling filter effluent; 35μ screen):
$a = 409$; $n = 0.782$

(2) Letchworth (clarified activated sludge effluent; 23μ screen):

a. 15 psi backwash: $a = 1.85 \times 10^{21}$; $n = 5.68$

b. 50 psi backwash: $a = 1.36 \times 10^{22}$; $n = 5.97$

The parameters $(X_o^s/q)$ vs. S/R are plotted in Figures V-4 for the Harpenden Study and Figure V-5 for the studies at Letchworth. The best correlation was obtained with the Harpenden data (Figure V-4) but the Letchworth data sets for both backwash pressures also showed positive correlation with the proposed relationship of Equation V-4. The constants obtained for the linearized form of Equation V-4 were as follows:

(1) Harpenden: $b = 0.00185$; $c = 0.0000777$

(2) Letchworth:

a. 15 psi backwash: $b = 0.00326$; $c = 0.0001$

b. 50 psi backwash: $b = 0.00953$; $c = 0.0003$

Results

The empirical equations established above are plotted in Figure V-6 and V-7 to illustrate the variation of the parameters $(X_I^s/X_o^s)$ and $(q/X_o^s)$ with (S/R) for the two types of effluents. It is readily apparent from the curves in Figure V-6 that the solids removal efficiency of the microscreen varies significantly with the solids loading factor, the screen size, and the type of solids being separated. Solids removal efficiency $(X_I^s/X_o^s)$ varied from 55 to 85 percent for the trickling filter effluent as S/R decreased from 0.00033 to 0.00005 lb/sq ft, and varied from three to 72 percent for the activated sludge effluent as S/R decreased from 0.0004 to 0.00007 lb/sq ft.

The curves plotted in Figure V-7 also show a striking difference in the normalized hydraulic loading parameter $(q/X_o^s)$ as a function of the solids loading factor, type of solids being separated, screen size,

and backwash efficiency. The $q/X_o^s$ factor was about 60 percent greater for activated sludge effluent (15 psi backwash) than for trickling filter effluent at a given S/R level, and was about 80 percent greater for activated sludge effluents at 50 psi backwash than at 15 psi. Thus, while $q/X_o^s$ varied significantly between types of solids, a much greater variation was observed for the same type of solids and screen size simply by increasing backwash efficiency.

## EVALUATION OF RELATIONSHIPS

### Implications

The empirical relationships provide a basis for examining the following implications within the systems context of microscreening:

(1) Solids characteristics: solids characteristics are manifested in terms of the class of mechanisms (surface screening or depth separation) operative in the filter medium.

(2) Screen size: there exists an appropriate screen size to optimize the initial trapping of a sufficient number of large particles to *catalyze* cake formation in order to enhance the trapping of smaller particles.

(3) Backwash: an increase in the backwash efficiency can effect a reduction in the residual headloss *carried* on the filtration medium through the backwash cycle.

(4) Solids loading factor: a change in the solids loading factor (S/R) adjusts the surface density of retained solids and causes a shift in the effective pore diameter of *particle trapping* character of the filter medium as well as in the aggregate headloss character of the filter medium. Each of the above implications can be considered with the data presented and empirical relationships established in Figures V-1 to V-7.

### Solids Characteristics and Screen Size

The initial implications on solids character and screen size can be examined by considering the constants n and a. High n values were

obtained with the clarified activated sludge effluent, the solids of which are expected typically to have a bimodal particle size distribution. The results indicate that for the combination of type of particles screened, screen size selected, and operation conditions employed, the initial capture of cake-forming solids was sufficient to effect the capture and retention of a significant fraction of the influent suspended solids. The n values for clarified activated sludge effluent were 5.7 to 6.0. In contrast an n value of 0.782 was obtained for the unsettled trickling filter effluent, which is believed to contain primarily bulky solids removable by screening. Thus, n is indicated as a parameter reflecting the class of solids separation mechanism operative for the type of particles removed and the selected operating conditions. High n values are indicative of depth or cake filtration; low n values obtain for surface or screening filtration. Corollary to the above, the constant a reflects the effectiveness of the screen and cake in retaining smaller particles at an early stage of the screening cycle. The solids removal efficiency ($X_1^s/X_0^s$) was much greater in the normal (S/R) operating range for microscreening of activated sludge effluents with a 23μ screen (a $>10^{21}$) than for trickling filter effluents (35μ screen; a = 409).

Another implication of the high a and n values for the clarified activated sludge effluent is that solids removal efficiency is very responsive to the solids loading factor. The relationship show for clarified activated sludge effluent in Figure V-6 suggests that $X_1^s/X_o^s$ is less than 10 percent (i.e., the actual solids removal is greater than 90 percent) at a solids loading factor in excess of 0.00028 lb/sq ft. This observation implies that the solids loading factor is a sensitive operational parameter for effluent quality control with solids suspension characterized by high n values, as was also suggested by Lynam *et al* (Reference V-1).

In reference to the systems context for microscreening the above observations suggest that a and n are parameters descriptive of the solids character and screen size and that the magnitudes of the solids character and behavioral responses of the solids retention and filter

medium elements. Without additional information it cannot be stated whether the values of a and n presented in the present study for activated sludge and trickling filter effluents are predictive of microscreen performance with other streams of similar solids. However, future information development on the microscreening process should be done in a context which at least permits a and n to be determined for the specific applications. Only in this manner can the predictive utility of the proposed empirical relationships be established.

Backwash

An increase in backwash pressure from 15 to 50 psi effected about an 80 percent increase in the normalized hydraulic loading parameter with the same clarified activated sludge effluent (Figure V-7). The foremost implication of this observation relative to the systems context is that backwash efficiency has a significant impact on the headloss characteristics of the filter medium. The impact on headloss character is realized by an adjustment of the residual surface density carried through the backwash cycle. Thus, improved backwash efficiency is suggested and has been used as a means of increasing the hydraulic capacity of microscreens in specific applications.

Solids Loading Factor

The solids loading factor is explicitly a function of specific hydraulic loading rate, influent suspended solids concentration, and rate of screen rotation. The solids loading factor can be related implicitly with the solids retention and filter medium elements of the systems context. A key question in the implicit relationships is how the implied changes in solids retention and filter medium affect the mechanism controlling solids removal. Either of two cases may obtain:

(1) No change occurs in the class of control mechanism (whether screen or cake filtration) as the S/R factor changes; i.e., the only change in the process will be a change in $q/X_o^s$ and $X_l^s/X_o^s$ as predicted in Equations V-2 and V-4, but no changes in a or n will occur.

(2) A shift occurs in the class of control mechanism with a resultant shift in the constants a and n.

In the two cases analyzed (at Letchworth and Harpenden) a single set of a and n values was obtained in each case over the entire S/R operating range. That is, a single class of mechanisms controlled in each case. Thus, it is unknown with the present information base whether or not Case 2 can actually occur.

Utility of Relationships

The empirical relationships for solids removal efficiency and hydraulic loading have provided insight both for defining the role of the deterministic model and for evaluating the performance of microscreens. It is apparent from this review that the role of the deterministic model for the microscreen will be to provide an integration of the interactions between and among the elements of solids input rate, solids character, solids retention, and filter medium in the systems context for microscreens. The foremost interactions requiring consideration are: the quantitative routing of particles onto and from the surface of the filler (screen); and prediction of the spatially variant headloss characteristics of the resultant filter medium. With an initial deterministic framework for routing of solids of varying particle sizes and prediction of headloss character of the filter medium thus formed, one can then proceed to consider empirically or deterministically the impact of factors such as particle shear, cake compressibility, and backwash efficiency on predicted microscreen performance. It is apparent from this review that the role of the deterministic model for the microscreen will be to provide an integration of the interactions between and among the elements of solids input rate, solids character, solids retention, and filter medium in the systems context for microscreens. The foremost interactions requiring consideration are: The quantitative routing of particles onto and from the surface of the filler (screen); and prediction of the spatially variant headloss characteristics of the resultant filter medium. With an initial deterministic framework for routing of solids of varying particle sizes and prediction of headloss character of the filter medium thus formed, one can then proceed to consider empirically or deterministically the impact of factors such as particle shear, cake compressibility, and

backwash efficiency on predicted microscreen performance.

Although the empirical relationships are not expected to be as specific and utilitarian as the anticipated deterministic model they could be used to establish both design and operating criteria for the microscreening process. Input for such an approach would require; establishing the values of the parameters a and n for the solids suspension of concern; a statement of treatment objectives and input flow and suspended solids levels for the wastewater; and a statement of the operational constraints of the selected or designated machine. With this basic information, one could proceed sequentially to:

(1) Compute the desired operational range of solids loading factors (S/R) for the application and selected screen.

(2) Compute the range of normalized hydraulic loading parameters ($q/X_o^S$) for the operating range of S/R value.

(3) Define the range of specific hydraulic flow rates which can be expected.

(4) Select the required area of fabric and the appropriate size of machine.

(5) Select rate of rotation, headloss level, and backwash rate and pressure for initial operation.

## CHAPTER V

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V-3 Truesdale, G. A., Birkbeck, A. E., Snow, D., *"A Critical Examination of Some Methods of Further Treatment of Effluents From Percolating Filters"*, Journal Institue of Sewage Purification (July 1963).

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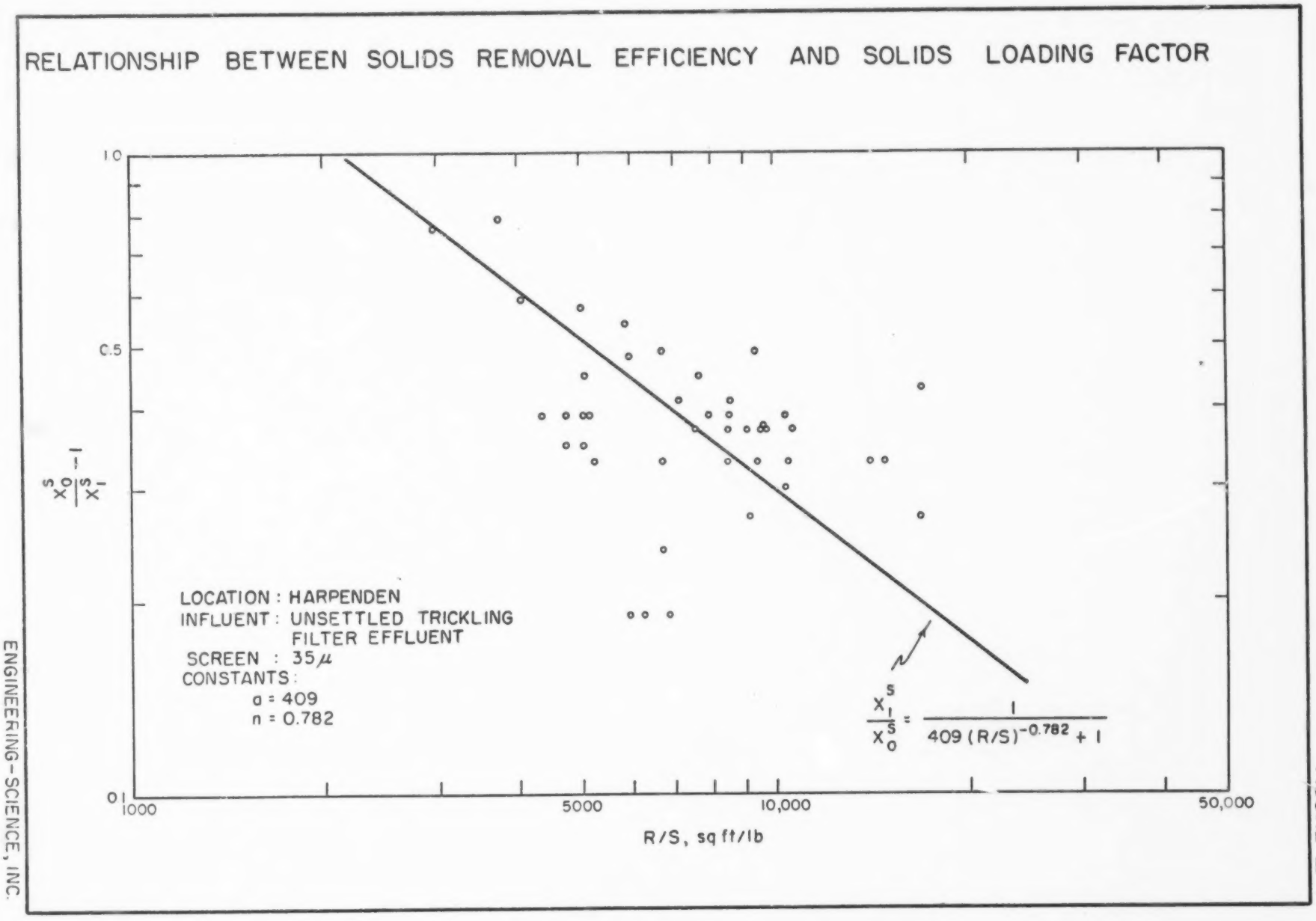
RELATIONSHIP BETWEEN SOLIDS REMOVAL EFFICIENCY AND SOLIDS LOADING FACTOR
1.0
0.5
0.1
1000
5000
10,000
50,000
R/S, sq ft/lb
$1 - \frac{X_o^s}{X_i^s}$
LOCATION : HARPENDEN
INFLUENT : UNSETTLED TRICKLING FILTER EFFLUENT
SCREEN : 35μ
CONSTANTS :
a = 409
n = 0.782
$\frac{X_i^s}{X_o^s} = \frac{1}{409\,(R/S)^{-0.782} + 1}$

FIGURE V-1

FIGURE V-2

# RELATIONSHIP BETWEEN SOLIDS REMOVAL EFFICIENCY AND SOLIDS LOADING FACTOR

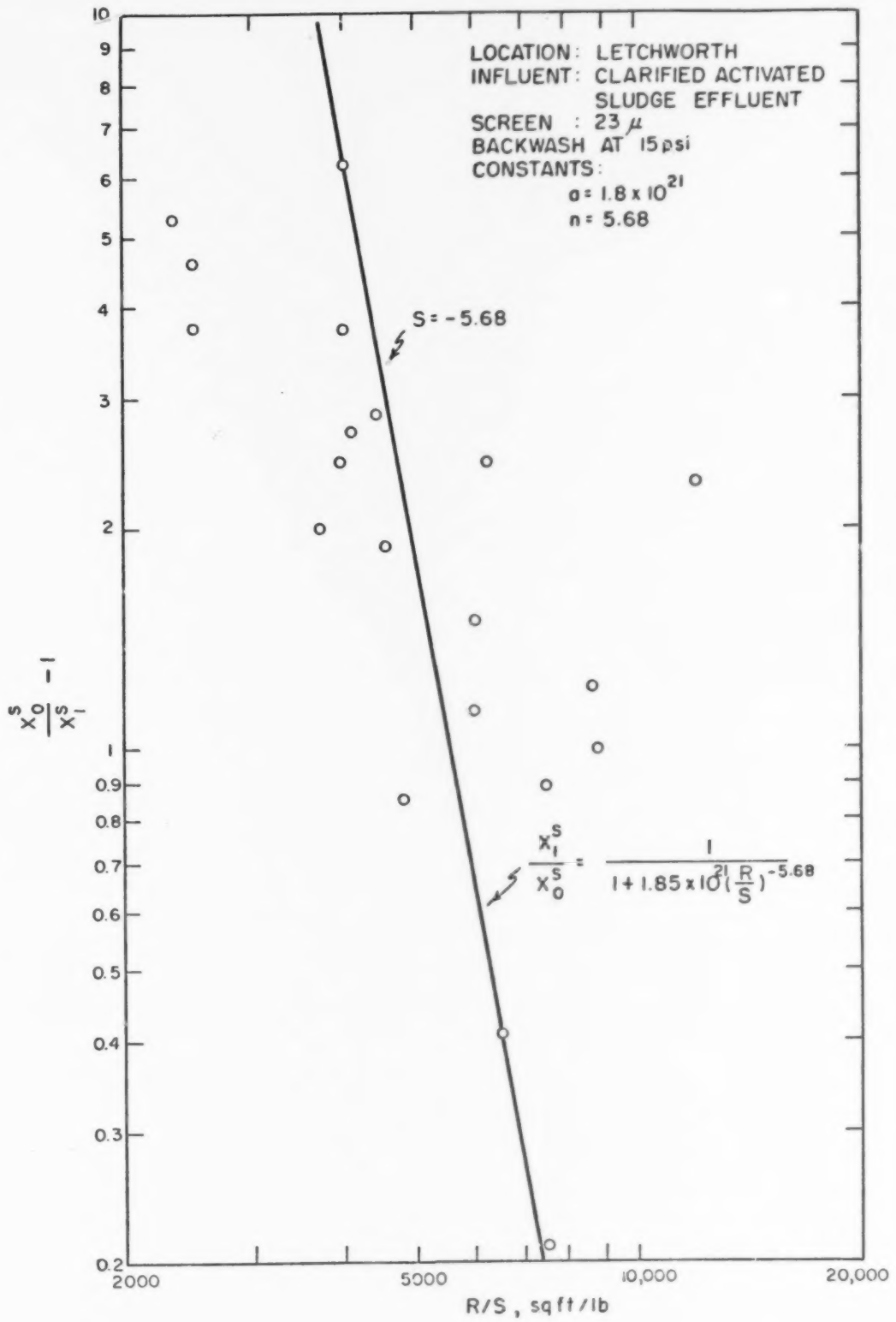


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FIGURE V-3

# RELATIONSHIP BETWEEN SOLIDS REMOVAL EFFICIENCY AND SOLIDS LOADING FACTOR

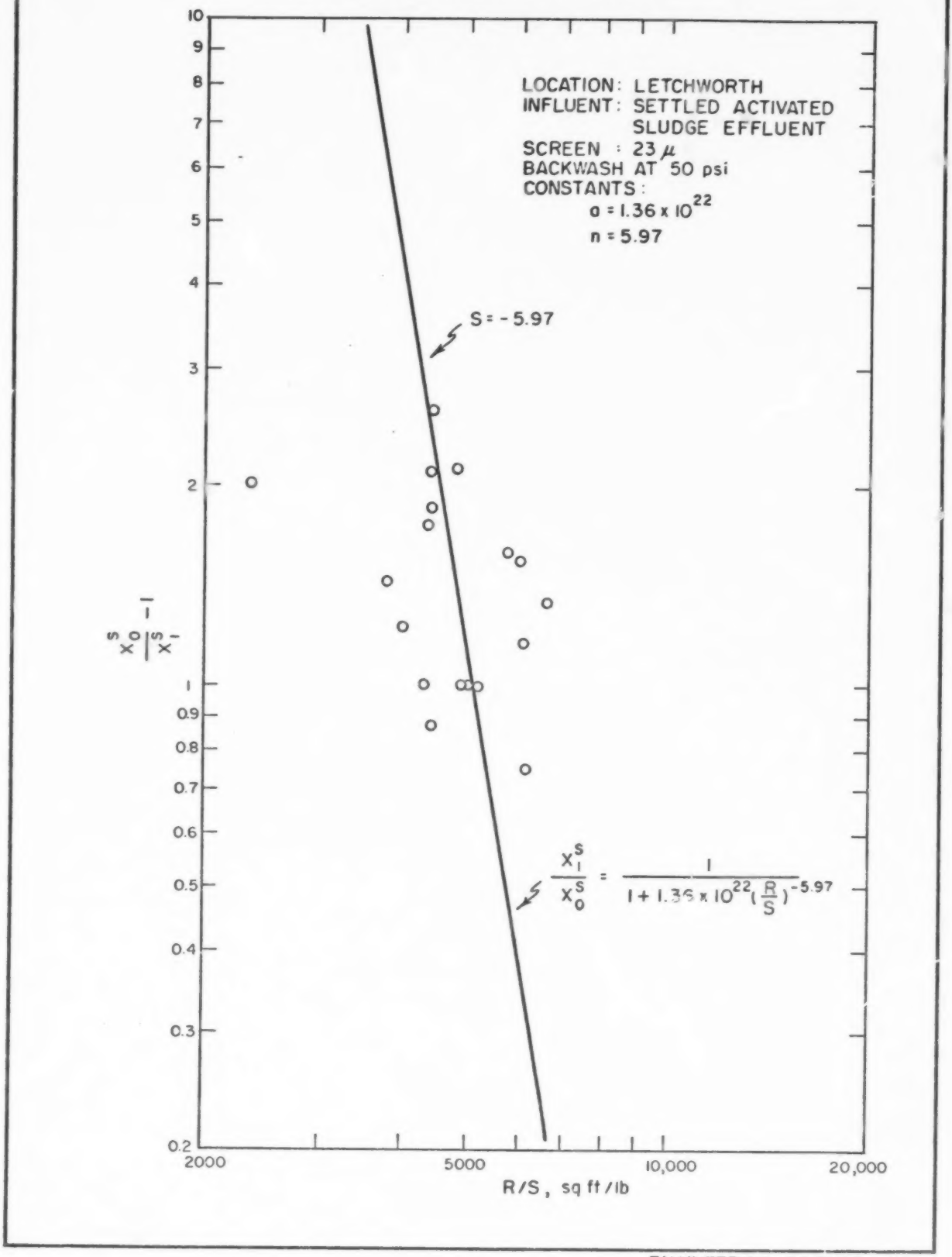


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FIGURE V-4

# RELATIONSHIPS BETWEEN NORMALIZED HYDRAULIC LOADING FACTOR AND SOLIDS LOADING FACTOR

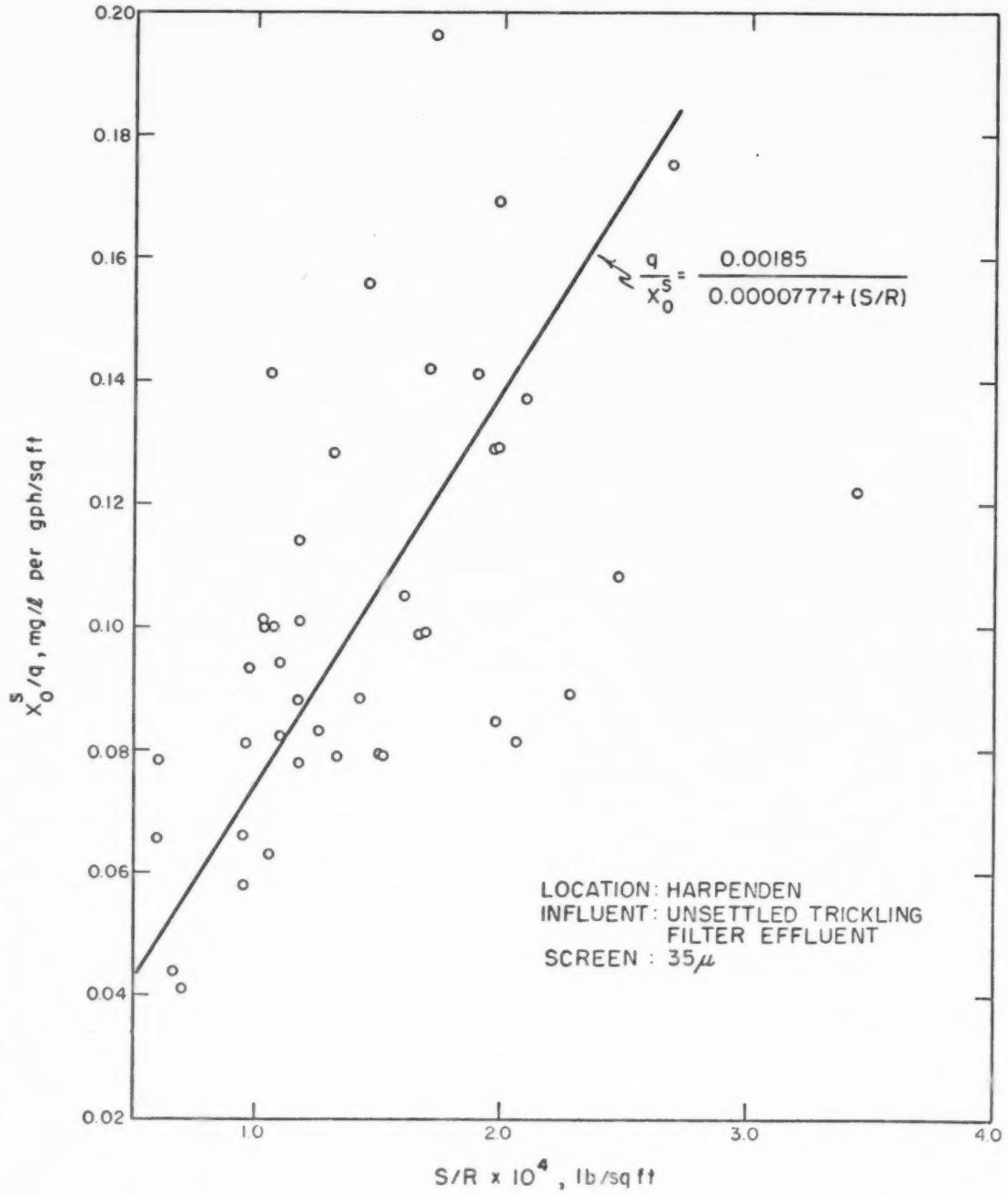




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FIGURE V-5

# RELATIONSHIPS BETWEEN NORMALIZED HYDRAULIC LOADING FACTOR AND SOLIDS LOADING FACTOR

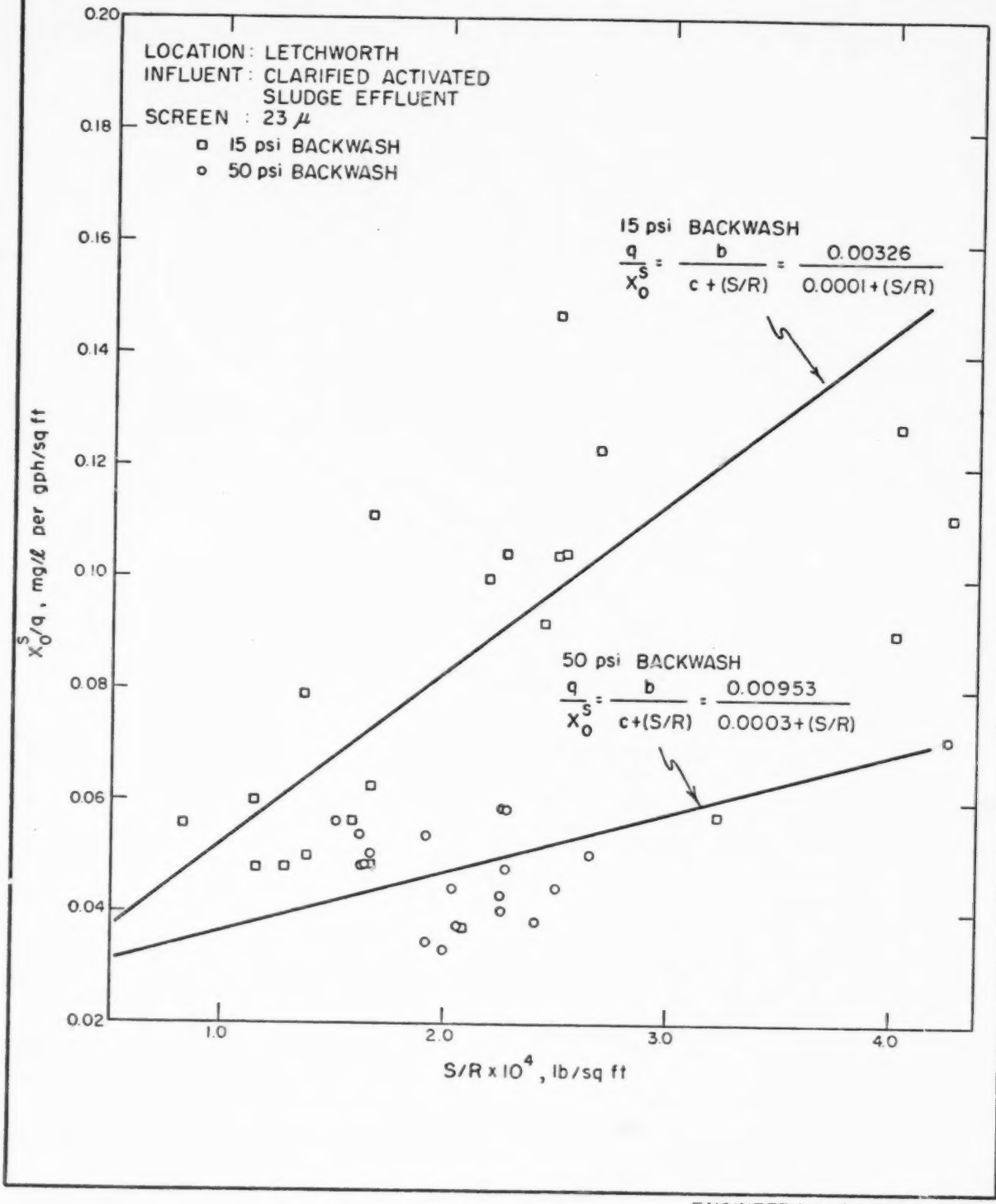




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FIGURE V-6

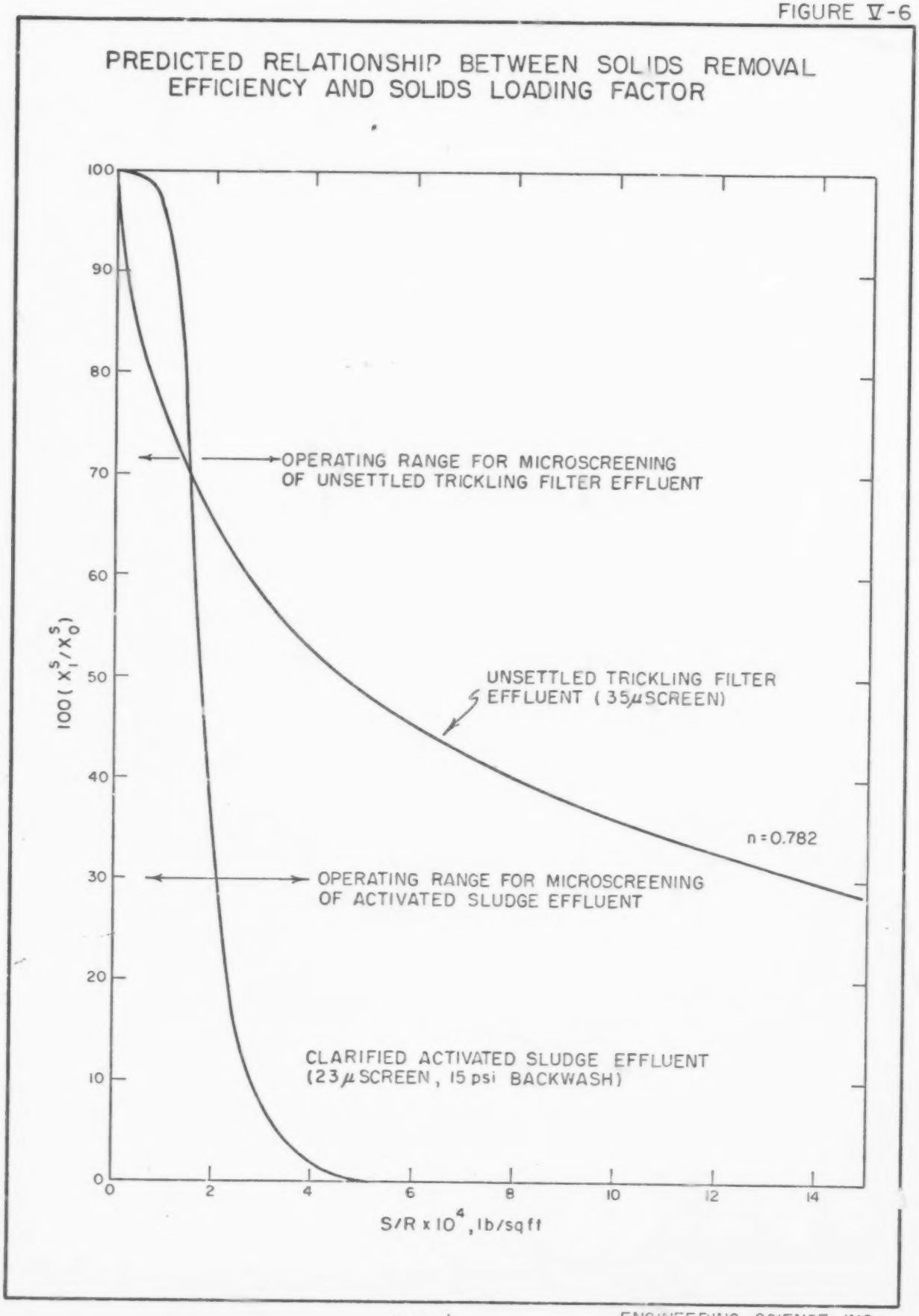
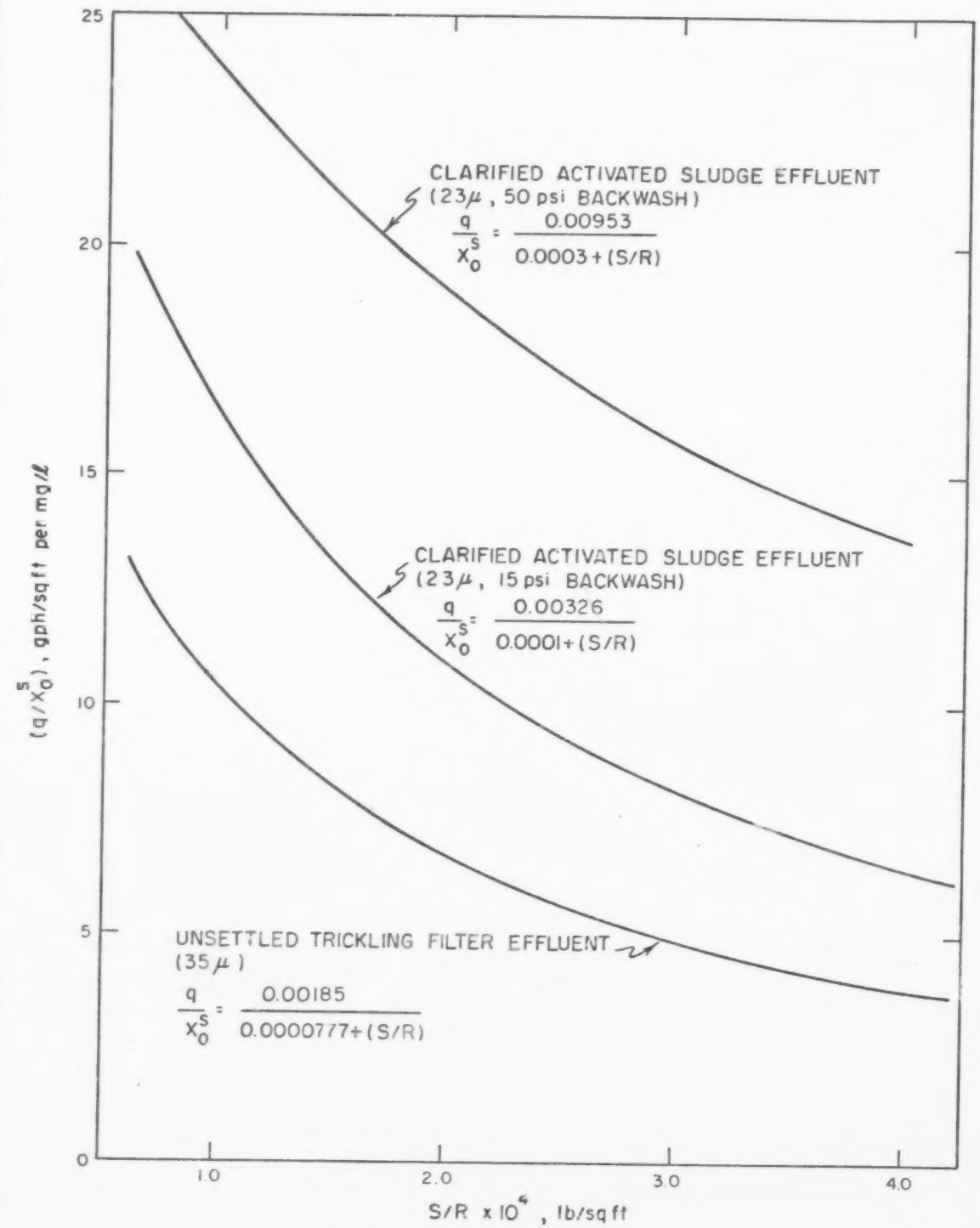

PREDICTED RELATIONSHIP BETWEEN SOLIDS REMOVAL EFFICIENCY AND SOLIDS LOADING FACTOR
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
100 ( X_1^S / X_0^S )
S/R x 10^4, lb/sq ft
OPERATING RANGE FOR MICROSCREENING OF UNSETTLED TRICKLING FILTER EFFLUENT
UNSETTLED TRICKLING FILTER EFFLUENT (35μ SCREEN)
n = 0.782
OPERATING RANGE FOR MICROSCREENING OF ACTIVATED SLUDGE EFFLUENT
CLARIFIED ACTIVATED SLUDGE EFFLUENT (23μ SCREEN, 15 psi BACKWASH)

FIGURE V-7

## PREDICTED RELATIONSHIPS NORMALIZED HYDRAULIC LOADING PARAMETER VS SOLIDS LOADING FACTOR



# CHAPTER VI
# SUMMARY, CONCLUSION, AND RECOMMENDATIONS

## SUMMARY

The microscreen process has been described as a sequence of interacting elements which function to convert, separate, or dispose of the solids in the liquid stream. A conceptual dynamic model has been proposed as a systems context for integrating the elements of the microscreen process and for guiding the use and evaluation of the process. The structure of the model was developed by an examination of the process, and the behavior of the process and its components is determined by the nature of the interaction between components. The objective functions for the conceptual model are: desired liquid throughput rate; desired solids emission rate; and permissible headloss. The conceptual model distinguish elementally between solids input rate, solid retention (on a *filler* or screen), and filter medium. The filter medium is the *milieu* of components (water, dissolved colloidal, and suspended solids, and the filter) in which mechanisms of separation (inertial forces, electroforces, concentration forces, and chemical forces) are operative, and is the element in which solids removal is effectuated and headloss is generated.

A critical review of the solids removal mechanisms potentially operative in the microscreen process has been presented. The mechanisms examined include: mechanical screening; gravity settling; interception; impaction; Brownian diffusion; molecular forces; electrostatic and electrokinetic forces; and chemical forces. The mechanisms were viewed as describing either a transport step (in which particles are moved to the surface of the media) or an attachment step (in which the particles adhere to the media). The synthesis of the evaluation of the mechanisms was that no data or theoretical analyses presently available indicate that one mechanism is universally responsible for particle removal, and that it is not yet possible to show quantitatively which mechanism may be controlling in the transport and attachment steps under any given set of physio-chemical conditions. Because of these reasons, only one mechanism, mechanical screening, was selected for use in the deterministic microscreen model being developed in the present study.

The aforementioned systems context was used as a background framework for evaluating available information on the design and performance of the microscreen process for water and wastewater treatment applications. Inasmuch as much of the information required for design of the microscreen has been held proprietary (e.g., selection of screen size, backwash capacity, and surface area), the designer has had little alternative but to rely on the manufacturer. As a result, the tradition has arisen that the designer *per se* has had very little concern for a basic knowledge of process fundamentals. As a result, there is little published information on how to design microscreens, and each application of the microscreen has been viewed as unique rather than as an extension of process utility in a general framework.

The two primary design considerations have been the hydraulics (determining the relative capacity of an installation) and solids removal efficiency. The work of Boucher has frequently been used in formulating headloss as a function of volume screened, the common parameter being the Filterability Index of the suspended solids separated in the screening. The concept of a Filterability Index has been a principle source of confusion in the technology of Boucher, primarily because there exists no published information correlating the Filterability Index with parameters characterizing the type and size of particles being removed and the solids retention on the filter (screen). Solids removal efficiency depends primarily on expediting the formation of a sufficient base of larger particles during the screening cycle to effect, in turn, a capture of finer solids. The point of onset of a threshhold level of cake formation is a function of the combination of screen size, particle size distribution and type, and the operating variables used in the specific process application.

Performance of specific microscreen installations has been tracked variously by : liquid balances; solids balances; screen and solids character; and screen loading rates. Very few of the applications were found to have been described with totality of the information indicated above; in fact detailed solids balances were reported in only two references in the entire body of literature, and the role of particle size distribution was considered in only one reference. The generally

sketchy performance information was evaluated with respect to the proposed systems context, and lead to the following implications:

(1) Particle removal efficiency increases with increasing solids input rate, insofar as the solids input rate does not adversely affect the filter medium.

(2) Liquid throughput rate is not limited by solids input rate but rather by the headloss characteristics of solids retained on the filter (i.e., the filter medium).

Based on these and other implications on microscreener performance, two empirical relationships relating solids removal efficiency with (1) a solids loading factor, and (2) a normalized hydraulic loading factor were proposed and substantiated using data developed in separate studies on unsettled trickling filter effluents and clarified activated sludge effluents. The empirical relationships thus established were used to provide a basis for rationalizing the role for the deterministic model as well as for designing and operating the microscreen process.

Based on the proposed systems context, the nature and utility of existing mechanisms for solids removal, and the general framework provided by the empirical relationships for microscreen performance, the indicated roles of the deterministic microscreen model being developed is the present study should be to provide for:

(1) Quantitative routing of particles onto and from the surface of the screen.

(2) Prediction of spatially variant headloss characteristics of the resultant filter medium.

## CONCLUSIONS

Based on an analysis of information presently available, it is concluded that no consistent systems framework has been provided for developing general and transferable understanding of the process. It is also concluded that the present understanding of operative mechanisms in the microscreening process is insufficient to permit the selection of any mechanism other than simple mechanical screening as the mechanism for

the deterministic mathematical model in the study.

## RECOMMENDATIONS

The recommendations of the stat-of-the-art evaluation are as follows:

(1) The role of the deterministic model for the study should be to provide an integration of the interactions between and among the elements of solids input rate, solids character, solids retention, and filter medium on the systems context. The most important interactions to be considered are the quantitative routing of particles onto and from the surface of the screen and the prediction of the spatially variant head-loss characteristics of the filter medium thereby formed.

(2) Future study of the microscreening process should be done with the objective of developing basic and thorough descriptions of liquid and solid balances for each specific application so that microscreen performance information has general rather than point utility.

# APPENDIX A

## BASIC DATA FOR EMPIRICAL MODEL

TABLE A-1

MICROSCREEN OPERATION AT HERPENDEN

WITH UNSETTLED TRICKLING FILTER EFFLUENT

AND 35 μ SCREEN

| Date | $X_1^s$ (mg/l) | $X_o^s$ (mg/l) | Q (Imgd) | S (lb/day) | S/R (lb/sq ft $10^{+4}$) | R/S (sq ft/lb) | $\frac{X_1^s}{X_o^s}$ | $\frac{X_o^s}{X_1^s}-1$ | $q/X_o^s$ (gph/ft$^2$/mg/l) | $q$ gph/ft$^2$ | $X_{0/9}^s$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 April 62 | 12 | 17 | 0.18 | 28.8 | 1.42 | 7,040 | .71 | .41 | 11.3 | 113 | .0885 |
| 14 April | 18 | 25 | 0.18 | 40.0 | 1.97 | 5,070 | 72 | .39 | 7.7 | 192 | .129 |
| 21 April | 18 | 25 | 0.18 | 40.0 | 1.97 | 5,070 | 72 | .39 | 7.7 | 192 | .129 |
| 28 April | 16 | 19 | 0.15 | 29.5 | 1.46 | 5,880 | 84 | .19 | 6.4 | 121 | .156 |
| 5 May | 18 | 24 | 0.16 | 38.4 | 1.89 | 5,280 | 75 | .33 | 7.1 | 170 | .141 |
| 12 May | 20 | 27 | 0.15 | 40.5 | 1.99 | 5,020 | 74 | .35 | 5.9 | 160 | .169 |
| 19 May | 16 | 19 | 0.17 | 32.4 | 1.60 | 6,270 | 84 | .19 | 9.5 | 180 | .105 |
| 26 May | 16 | 19 | 0.18 | 34.3 | 1.69 | 5,920 | 84 | .19 | 10.1 | 190 | .099 |
| 2 June | 18 | 25 | 0.17 | 42.5 | 2.09 | 4,780 | 72 | .39 | 7.3 | 180 | .137 |
| 9 June | 18 | 32 | 0.17 | 54.4 | 2.68 | 3,730 | 56 | .79 | 5.7 | 180 | .175 |
| 16 June | 17 | 30 | 0.23 | 69.0 | 3.44 | 2,950 | 57 | .76 | 8.2 | 245 | .177 |
| 23 June | 10 | 15 | 0.17 | 25.5 | 1.26 | 7,960 | 67 | .49 | 12.0 | 180 | .083 |
| 30 June | 11 | 15 | 0.14 | 21.0 | 1.07 | 9,670 | 73 | .37 | 10.0 | 150 | .100 |
| 7 July | 14 | 19 | 0.22 | 41.8 | 2.06 | 4,870 | 74 | .35 | 12.3 | 230 | .0812 |
| 14 July | 15 | 21 | 0.22 | 46.3 | 2.28 | 4,380 | 72 | .39 | 11.2 | 235 | .0892 |
| 21 July | 13 | 19 | 0.21 | 39.9 | 1.96 | 5,090 | 69 | .45 | 11.8 | 220 | .0848 |
| 28 July | 15 | 24 | 0.21 | 50.3 | 2.48 | 4,040 | 63 | .59 | 9.3 | 223 | .108 |
| 4 Aug | 11 | 15 | 0.17 | 25.5 | 1.26 | 7,970 | 73 | .37 | 12.0 | 180 | .083 |
| 11 Aug | 13 | 19 | 0.18 | 34.2 | 1.68 | 5,930 | 68 | .47 | 10.1 | 190 | .099 |
| 18 Aug | 13 | 16 | 0.19 | 30.5 | 1.50 | 6,670 | 81 | .24 | 12.6 | 200 | .079 |
| 25 Aug | 13 | 19 | 0.14 | 26.7 | 1.31 | 7,620 | 69 | .45 | 7.8 | 150 | .128 |

TABLE A-1 (Cont'd)

| Date | $X_1^s$ (mg/l) | $X_o^s$ (mg/l) | Q (Imgd) | S (lb/day) | S/R (lb/sq ft $10^{+4}$) | R/S (sq ft/lb) | $\frac{X_1^s}{X_o^s}$ | $\frac{X_o^s}{X_1^s}-1$ | $q/X_o^s$ (gph/ft$^2$/mg/l) | q gph/ft$^2$ | $X_{o/9}^s$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Sept | 10 | 14 | 0.17 | 23.8 | 1.17 | 8,530 | 72 | .39 | 12.9 | 180 | .078 |
| 8 Sept | 6 | 8 | 0.18 | 14.4 | 0.71 | 14,100 | 75 | .33 | 24.0 | 190 | .041 |
| 15 Sept | 6 | 8 | 0.17 | 13.6 | 0.67 | 14,900 | 75 | .33 | 22.6 | 180 | .044 |
| 22 Sept | 9 | 12 | 0.18 | 21.6 | 1.06 | 9,410 | 75 | .33 | 16.0 | 190 | .063 |
| 29 Sept | 11 | 15 | 0.15 | 22.5 | 1.11 | 9,030 | 73 | .37 | 10.6 | 160 | .094 |
| 6 Oct | 11 | 14 | 0.16 | 22.4 | 1.10 | 9,080 | 79 | .27 | 12.2 | 170 | .082 |
| 13 Oct | 15 | 23 | 0.15 | 34.5 | 1.70 | 5,880 | 65 | .54 | 7.0 | 160 | .142 |
| 20 Oct | 12 | 17 | .14 | 23.8 | 1.17 | 8,530 | 71 | .41 | 8.8 | 150 | .114 |
| 27 Oct | 12 | 18 | .12 | 21.6 | 1.06 | 9,390 | 67 | .49 | 7.1 | 130 | .141 |
| 3 Nov | 11 | 15 | .14 | 21.0 | 1.03 | 9,670 | 73 | .37 | 9.9 | 150 | .101 |
| 10 Nov | 7 | 9 | .13 | 21.1 | .60 | 16,800 | 78 | .27 | 15.4 | 140 | .065 |
| 17 Nov | 10 | 14 | .14 | 19.6 | .97 | 10,300 | 72 | .39 | 10.7 | 150 | .093 |
| 24 Nov | 8 | 11 | .18 | 19.1 | .94 | 10,600 | 73 | .37 | 17.4 | 190 | .058 |
| 1 Dec | 7 | 10 | .12 | 12.0 | .59 | 16,900 | 70 | .43 | 12.8 | 130 | .078 |
| 8 Dec | 11 | 15 | .14 | 21.1 | 1.04 | 9,630 | 73 | .37 | 9.9 | 150 | .101 |
| 15 Dec | 10 | 13 | .15 | 19.5 | .96 | 10,400 | 77 | .30 | 12.3 | 160 | .081 |
| 22 Dec | 9 | 12 | .17 | 19.4 | .96 | 10,500 | 75 | .33 | 15.1 | 180 | .066 |
| 29 Dec | 11 | 15 | .16 | 24.0 | 1.18 | 8,450 | 73 | .37 | 11.4 | 170 | .088 |
| 5 Jan | 11 | 15 | .18 | 27.0 | 1.33 | 7,530 | 73 | .37 | 12.8 | 190 | .079 |
| 12 Jan | 12 | 16 | .19 | 30.4 | 1.50 | 6,680 | 75 | .33 | 12.6 | 200 | .079 |
| 19 Jan | 12 | 16 | .15 | 24.0 | 1.18 | 8,450 | 75 | .33 | 9.9 | 160 | .101 |
| 26 Jan | 18 | 27 | .13 | 35.1 | 1.73 | 5,780 | 67 | .60 | 5.1 | 140 | .196 |

NOTES: See Next Page

TABLE A-1 (Cont'd)

NOTES:

(1) 1 Imperial Gallon = 1.2 US gallons = 10 lb
(2) Drum area = 5 ft diamter x 3 ft wide x $\pi$ = 47 sq ft
(3) Drum peripheral speed = 47 ft/min
(4) R (daily rate of screen)presentation) = 203,000 sq ft/day
(5) Q = Liquid throughput rate
(6) q = specific liquid throughput rate, gph/sq ft
    equal to Q(Igpd) : (1.2 x 47 x 3)
(7) Data From:
    Truesdale, G. A., Birkbeck, A. E., Shaw, D., *"A Critical Examination of Some Methods of Further Treatment of Effluents From Percolating Filters"*, July 1963.

TABLE A-2

MICROSCREEN OPERATION AT LETCHWORTH

WITH CLARIFIED ACTIVATED SLUDGE EFFLUENT

AND 23 μ SCREEN

| Date | $X_1^s$ (mg/l) | $X_o^s$ (mg/l) | Q (Igph/ft$^2$) | S (lb/hr) | S/R (lb/ft$^2$/ x $10^4$) | R/S (ft$^2$/lb) | $\frac{X_1^s}{X_o^s}$ | $\frac{X_o^s}{X_1^s}-1$ | q (gph/ft$^2$) | $q/X_o^s$ (gph/ft$^2$ mg/l) | $X_o^s/q$ (mg/l/ gph/sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 April 66 | 7 | 24 | 190 | 2.14 | 2.53 | 3,950 | .29 | 2.45 | 230 | 9.58 | .104 |
| | 8 | 20 | 150 | 1.41 | 1.67 | 6,000 | .40 | 1.50 | 180 | 9.00 | .111 |
| | 7 | 15 | 200 | 1.41 | 1.67 | 6,000 | .47 | 1.13 | 240 | 16.00 | .0625 |
| | 10 | 12 | 200 | 1.13 | 1.34 | 7,470 | .83 | 0.71 | 240 | 20.00 | .0500 |
| | 6 | 12 | 170 | 0.96 | 1.14 | 8,800 | .50 | 1.00 | 200 | 16.67 | .0600 |
| | 3 | 10 | 150 | 0.705 | 0.83 | 12,000 | .30 | 2.33 | 180 | 18.00 | .0555 |
| | 5 | 11 | 190 | 0.98 | 1.16 | 8,650 | .45 | 1.22 | 230 | 20.91 | .0478 |
| | 4 | 14 | 205 | 1.35 | 1.60 | 6,260 | .29 | 2.45 | 250 | 17.86 | .0563 |
| | 7 | 13 | 290 | 1.77 | 2.09 | 4,780 | .54 | 0.85 | 350 | 26.92 | .0371 |
| | 9 | 20 | 290 | 2.72 | 3.22 | 3,110 | .45 | 1.22 | 350 | 17.50 | .0572 |
| | 7 | 33 | 220 | 3.41 | 4.03 | 2,480 | .21 | 3.76 | 260 | 7.88 | .127 |
| | 5 | 32 | 240 | 3.61 | 4.27 | 2,340 | .16 | 5.25 | 290 | 9.06 | .111 |
| | 5 | 28 | 260 | 3.42 | 4.03 | 2,480 | .18 | 4.55 | 310 | 11.07 | .0900 |
| | 6 | 23 | 180 | 1.91 | 2.26 | 4,430 | .26 | 2.85 | 220 | 9.57 | .104 |
| | 8 | 22 | 180 | 1.86 | 2.20 | 4,550 | .36 | 1.88 | 220 | 10.00 | .100 |
| | 9 | 27 | 180 | 2.28 | 2.70 | 3,710 | .33 | 2.00 | 220 | 8.15 | .123 |
| | 55 | 24 | 190 | 2.11 | 2.50 | 4,000 | .21 | 3.76 | 230 | 9.58 | .104 |
| | 4 | 28 | 160 | 2.11 | 2.50 | 4,000 | .14 | 6.15 | 190 | 6.79 | .147 |
| | 6 | 22 | 200 | 2.07 | 2.44 | 4,090 | .27 | 2.71 | 240 | 10.91 | .0917 |
| | 8 | 15 | 100 | 1.13 | 1.34 | 7,470 | .53 | 0.84 | 190 | 12.67 | .0790 |
| 25 Aug 66 | 10 | 13 | 230 | 1.40 | 1.66 | 6,050 | .71 | 0.41 | 280 | 21.54 | .0487 |

TABLE A-2 (Cont'd)

| Date | $X_1^s$ (mg/l) | $X_o^s$ (mg/l) | Q (Igph/ft$^2$) | S (lb/hr) | S/R (lb/ft$^2$/ x $10^4$) | R/S (ft$^2$/lb) | $\frac{X_1^s}{X_o^s}$ | $\frac{X_o^s}{X_1^s}-1$ | q (gph/ft$^2$) | $q/X_o^s$ (gph/ft$^2$ mg/l) | $X_o^s/q$ (mg/l/ gph/sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| High-Pressure Backwash Nozzles Installed | | | | | | | | | | | |
| 20 Oct 66 | 8.5 | 25.5 | 300 | 3.59 | 4.25 | 2,360 | .33 | 2.00 | 360 | 14.12 | .0708 |
| | 7.5 | 14.0 | 290 | 1.91 | 2.26 | 4,430 | .54 | 0.87 | 350 | 25.00 | .0400 |
| | 7.0 | 14.0 | 270 | 1.73 | 2.04 | 4,900 | .50 | 1.00 | 320 | 22.86 | .0437 |
| | 8.0 | 14.0 | 220 | 1.38 | 1.63 | 4,130 | .57 | 0.75 | 260 | 18.57 | .0538 |
| | 6.0 | 13.0 | 230 | 1.40 | 1.66 | 6,050 | .46 | 1.17 | 280 | 21.54 | .0487 |
| 24 Nov 66 | 5.0 | 13.0 | 240 | 1.47 | 1.74 | 5,750 | .38 | 1.60 | 290 | 22.31 | 0.0488 |
| | 5.5 | 14.0 | 230 | 1.41 | 1.67 | 6,000 | .39 | 1.54 | 280 | 20.00 | 0.0500 |
| 8 Dec 66 | 6.0 | 14.0 | 210 | 1.29 | 1.52 | 6,560 | .43 | 1.33 | 250 | 17.86 | 0.0560 |
| 19 Jan 67 | 4.0 | 14.5 | 280 | 1.91 | 2.26 | 4,430 | .28 | 2.63 | 340 | 23.45 | 0.0427 |
| | 4.0 | 12.5 | 300 | 1.76 | 2.08 | 4,810 | .37 | 2.13 | 360 | 28.80 | 0.0347 |
| | 6.0 | 12.0 | 300 | 1.69 | 2.00 | 5,010 | .50 | 1.00 | 360 | 30.00 | 0.0333 |
| | 6.0 | 12.0 | 290 | 1.63 | 1.92 | 5,200 | .50 | 1.00 | 350 | 29.17 | 0.0344 |
| | 7.0 | 14.0 | 300 | 1.97 | 2.32 | 4,300 | .50 | 1.00 | 360 | 25.71 | 0.0389 |
| | 7.0 | 15.5 | 290 | 2.11 | 2.50 | 4,000 | .45 | 1.22 | 350 | 22.58 | 0.0443 |
| | 7.0 | 17.0 | 280 | 2.24 | 2.65 | 3,780 | .41 | 1.43 | 340 | 20.00 | 0.0500 |
| | 6.0 | 16.5 | 250 | 1.94 | 2.30 | 4,350 | .36 | 1.75 | 300 | 18.18 | 0.0555 |
| | 7.5 | 15.0 | 230 | 1.62 | 1.92 | 5,220 | .50 | 1.00 | 280 | 18.67 | 0.0536 |
| | 5.5 | 17.0 | 240 | 1.92 | 2.27 | 4,400 | .32 | 2.09 | 290 | 17.06 | 0.0587 |
| 30 Mar 67 | 6.0 | 17.0 | 240 | 1.92 | 2.27 | 4,400 | .35 | 1.84 | 290 | 17.06 | 0.0587 |

NOTES: See Next Page

TABLE A-2 (Cont'd)

NOTES:

(1) 1 lgal - 1.2 US gal - 10 lb $H_2O$

(2) Drum Area = 5 x 3 x $\pi$ = 47 sq ft

(3) Drum peripheral speed = 47 ft/min

(4) R = 203,000 sq ft/day = 8,460 sq ft/hr

(5) Q = Liquid throughput rate

(6) q = specific liquid throughput rate, gph/sq ft equal to Q (Igpd) ÷ (1.2 x 47 x 3)

(7) Data From:

Truesdale, G. A., Birkbeck, A. E., *"Tertiary Treatment of Activated Sludge Effluent"* Journal Inst. of Water Pollution Control (Sept 1967).